Saskatchewan Research Council.
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DESALINATION OF BRACKISH WATER BY SPRAY FREEZING

Progress Report 1980 - 81

by

J. W. Spyker

SRC Technical Report No. 134

April, 1982

SRC PUBLICATION NO. E-835-2-B-82

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ABSTRACT

Spray freezing trials were conducted on Brackish groundwater containing 3316 parts per million total dissolved solids at the Blucher field site. Three spray areas were used; two with one spray head each, and a larger spray area with five spray heads. One of the smaller spray areas was fitted with a butyl membrane liner, the other was lined with polyethylene for this year only. The large unit was not lined. Total volumes sprayed were 691,000 and 577,000 Imperial gallons for the smaller units and 3,393,000 Imperial gallons for the multiple unit.

Very good results were obtained for the butyl membrane lined unit. Overall recovery of input water was 80 percent, with 72 percent of the input water being recovered as water containing less than 1000 parts per million total dissolved solids. Results from the unit lined with polyethylene (unlined in previous years) continued to be poor. Overall water recovery 87 percent, but the salinity of all samples was high, only two were below 2000 parts per million total dissolved solids. Somewhat better results were obtained for the multiple unit. Overall water recovery was 83 percent with 33 percent being recovered as water containing less than 1000 parts per million total dissolved solids and 76 percent being recovered as water containing less than 1500 parts per million total dissolved solids.

References on physiological effects of brackish water and on economic considerations are summarized in this report.

English, rather than metric, units are used to permit direct comparison with earlier progress reports.

TABLE OF CONTENTS

	Page
ABSTRACT	(i)
INTRODUCTION	1
SPRAY FREEZING FACILITIES	4
EXPERIMENTAL PROCEDURE	5
RESULTS	9
DISCUSSION OF SPRAY FREEZING RESULTS AND CONCLUSIONS	19
PHYSIOLOGICAL EFFECTS OF BRACKISH WATERS	31
ECONOMIC CONSIDERATIONS	33
RECOMMENDATIONS FOR FUTURE WORK	50
ACKNOWLEDGMENTS	55
REFERENCES	56
APPENDIX A - METEOROLOGICAL AND ICE MELT DATA	58

LIST OF FIGURES

Figure		Page
1	Quality and quantity of recovered water, Blucher lined	13
2	Quality and quantity of recovered water, Blucher unlined	14
3	Quality and quaniity of recovered water, Blucher multiple	15
4	Melting rates, Blucher lined	16
5	Melting rates, Blucher unlined	17
6	Melting rates, Blucher multiple	13

LIST OF TABLES

Table		Page
1	Input water analysis, Blucher	6
2	Details of spray freezing operations	7
3	Product quality and quantity, Blucher lined	10
4	Product quality and quantity, Blucher unlined	11
5	Product quality and quantity, Blucher multiple	12
6	Yields as percentage of input for various product salinities	22
7	Summary of weather data during 1980-81 spraying season.	27
8	Yearly temperature averages for the months of January, February and March	28
9	Recovery of salts and water at Blucher	29
10	Total dissolved solids and sodium reduction by eight different reverse asmosis systems in Sarasota County, Florida	34
11	Estimated costs (1980) for removal of TDS and sodium from drinking water	36
12	Construction costs, water treatment systems	37
13	Operation and maintenance costs	38
14	Utilities selected for cost impact studies	40
15	Estimated economic impacts for small systems	41
16	Unit costs	43
17	Water factory 21 capital and engineering costs	44
18	Water factory 21 - capital and operating costs ($/1000 m^3)	45
19	Comparative economic results of dual versus single water distribution systems	47

LIST OF TABLES (cont'd)

Table		Page
20	Maximum water quality design values	48
21	Weather variability	51
A1	Meteorological data	59
A2	Ice melt removals, Blucher lined 1981	64
A3	Ice melt removals, Blucher unlined 1981	66
A4	Ice melt removals, Blucher multiple 1981	68

INTRODUCTION

The Saskatchewan Research Council has been investigating water desalination by natural freezing for over 20 years. Reservoir freezing, layer freezing and spray freezing have been studied. Reservoir freezing and layer freezing have been described earlier (1), (2). This report and preceding reports (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13) deal with spray freezing.

Water can be desalinated by freezing because when a solution of an inorganic salt is cooled to the freezing point, essentially pure ice crystals form and the salts are concentrated in the remaining solution as long as solubility levels are not exceeded. As cooling continues, eventually the eutectic temperature for the particular composition is reached and complete solidification occurs. In order to separate the ice crystals and melt them to produce potable water, the mixture must remain above the eutectic temperature.

Spray freezing is a process in which brackish water is pumped continuously through a rotating sprinkler mounted on a vertical standpipe. Spraying rates are adjusted according to weather conditions so that enough heat of crystallization is given up to keep the temperature above the eutectic but enough ice is formed to produce a self-supporting ice mound. Above the eutectic temperature, the ice mound is porous and contains brine. The brine is heavier than the ice so it will drain out and additional brine will be flushed from the ice by the initial melt water which percolates through it. The brine is discarded and the remaining ice melt is collected and stored for use as potable water.

Brine cannot be completely separated from the ice because a fraction of the brine will cling to the ice crystal surfaces or be trapped within isolated pockets in the ice. Also, usually parts of the ice mound will be cooled below the eutectic temperature during bad weather.

Spray freezing is a relatively cheap desalination process, primarily because the refrigeration energy is free. Little labour would be required and capital costs would be low because the equipment is simple and confining structures for the ice mound would not be required. Costs estimates were prepared in 1972 (4), (5) and updated in 1975 (8). These showed that spray freezing costs compared favorably with those for reservoir freezing, layer freezing and commercial processes such as reverse osmosis and electrodialysis. The advantages of spray freezing relative to commercial processes will have increased since 1975 because of the rapid escalation of energy costs.

Because spray freezing uses natural refrigeration it is a winter operation, so the product produced in the spring must be stored for use during the year. Storage could be in surface reservoirs or underground in an existing aquifer. Surface reservoirs are expensive and some of the water is lost through evaporation and seepage or is not available because it is frozen during the winter. Thermal and biological degradation can also occur. Storage in an existing aquifer would be better, if such an aquifer is suitably located. The water could be recharged through wells or through infiltration reservoirs if the aquifer was shallow enough. Preliminary well recharge experiments at Blucher, Armley and Frontier were not encouraging but infiltration at Frontier gave excellent results (8), (9), (10), (11), (12), (13).

This report describes the spray freezing studies done during the 1980-81 season and summarizes literature on physiological effects of brackish waters and economic considerations.

SPRAY FREEZING FACILITIES

Spray freezing was conducted at only one site, Blucher, this year. A detailed description of the facilities was given in previous reports (6), (9), (11). Briefly, the facilities consist of a well, a water distribution system, a control building, three dyked spray areas and a holding pond. Water is pumped through buried lines from the well to the control building and from there to standpipes in each spraying area. The control building has equipment to measure, control and sample the water. One spray area is 116 ft. by 116 ft., has a single spray head, and is lined with butyl membrane. The second spray area also has a single spray head, is 136 ft. by 136 ft., and for this season was lined with polyethylene sheeting. For comparison with results from previous years, this unit will be referred to as the unlined unit. The polyethylene was installed late in 1980 and was held in place by gravel and ice; joints between sheets were not sealed. The third spray area is 243 ft. by 250 ft., unlined, and with five spray heads. The spray heads are arranged in a diamond pattern with one at the center and the other four on diagonal each about 65 ft. from the center. Brine and water are pumped from the spraying areas to a small butyl membrane lined holding pond from which they can be pumped to a nearby saline slough. The slough can be used for brine disposal without danger of groundwater contamination because it is, on balance, a groundwater discharge area.

The spray heads used were described in last year's progress report (13).

EXPERIMENTAL PROCEDURE

The average analysis of the Blucher well water is given in Table 1.

Spraying began on December 17, 1980 in the multiple spray area and the area lined with butyl membrane, and on January 6, 1981 in the area lined with polyethylene. Spraying stopped in all three on April 1, 1981. Details of the spraying period are given in Table 2, together with data from previous years.

Flow rates, water temperatures, maximum and minimum air temperatures and 'ilometres of wind were recorded every day or occasionally at two or three day intervals. Thermistors were frozen into the ice mound in the butyl membrane lined spray area and some ice temperatures were measured. Meteorological measurements continued during the meet period.

Melt water was pumped from the spray areas with automatic sump pumps. Volumes were measured and proportional samples were collected for chemical analysis. Dates of beginning and end of melt collection are given in Table 2.

TABLE 1

Input Water Analyses, Blucher, Parts per Million

Calcium	183
Magnesium	48
Sodium	817
Potassium	7.8
Iron	20
Manganese	1.1
Carbonate	0
Bicarbonate	480
Sulphate	1410
Chloride	349
Total Dissolved Solids	3316

TABLE 2

Details of Spray Freezing Operations

Site	Spraying Started	Spraying Stopped	Total Input Imp. Gal.	Average Input Rate Imp. Gal. per Min.	Date of First Melt Collection	Date of Completion of Melting
Outdoor Laboratory, Lined	Jan. 26, 1971	March 15, 1971	219,900	3.2[1]	Feb. 3, 1971	May 21, 1971
Outdoor Laboratory, Lined	Jan. 20, 1972	March 13, 1972	280,060	3.7	Feb. 2, 1972	May 31, 1972
Outdoor Laboratory, Unlined	Dec. 15, 1971	March 13, 1972	149,600	1.2[2]	March 13, 1972	May 5, 1972
Outdoor Laboratory, Lined	Jan. 8, 1973	March 15, 1973	293,370	3.07	March 8, 1973	May 30, 1973
Outdoor Laboratory, Unlined	Jan. 11, 1973	March 15, 1973	259,842	2.85[1]	March 8, 1973	May 23, 1973
Outdoor Laboratory, Lined	Dec. 6, 1973	March 29, 1974	551,417	3.39	April 1, 1974	June 30, 1974
Outdoor Laboratory, Unlined	Dec. 18, 1973	April 1, 1974	634,085	4.23	April 1, 1974	July 2, 1974
Outdoor Laboratory, Lined	Jan. 2, 1975	April 9, 1975	889,220	6.37	April 12, 1975	May 29, 1975
Outdoor Laboratory, Unlined	Dec. 10, 1974	April 9, 1975	1,156,110	6.69	April 12, 1975	June 23, 1975
Outdoor Laboratory, Lined	Dec. 22, 1975	March 18, 1976	814,300	6.50	March 24, 1976	May 28, 1976
Outdoor Laboratory, Lined	Jan. 4, 1977	April 6, 1977	628,730	4.64	April 6, 1977	May 8, 1977
Outdoor Laboratory, Unlined	Jan. 4, 1977	April 6, 1977	622,970	4.60	April 6, 1977	May 16, 1977
Outdoor Laboratory, Lined	Dec. 23, 1977	March 25, 1978	675,790	5.10	March 31, 1978	June 9, 1978
Outdoor Laboratory, Unlined	Dec. 23, 1977	March 25, 1978	680,440	5.14	March 31, 1978	June 9, 1978
Outdoor Laboratory, Lined	Dec. 19, 1978	April 4, 1979	707,190	4.63	March 20, 1979	June 6, 1979
Outdoor Laboratory, Lined	Dec. 27, 1979	March 27, 1980	631,660	4.82	March 30, 1980	June 10, 1980
Bruno, Lined	Dec. 11, 1972	March 16, 1973	534,870	3.84[3]	March 13, 1973	June 11, 1973
Bruno, Unlined	Jan. 16, 1973	March 16, 1973	348,470	4.10	March 13, 1973	June 1, 1973
Bruno, Lined	Dec. 4, 1973	April 3, 1974	881,530	5.10	April 8, 1974	July 1, 1974
Bruno, Unlined	Dec. 4, 1973	April 5, 1974	960,770	5.47	April 8, 1974	June 22, 1974
Bruno, Lined	Dec. 31, 1974	April 7, 1975	869,040	6.22	April 11, 1975	June 26, 1975
Bruno, Unlined	Dec. 31, 1974	April 7, 1975	998,220	7.15	April 11, 1975	June 12, 1975
Bruno, Lined	Dec. 4, 1975	March 26, 1976	960,530	5.90	March 27, 1976	June 10, 1976
Bruno, Unlined	Dec. 4, 1975	March 26, 1976	1,008,780	6.20	March 27, 1976	June 10, 1976
Bruno, Lined	Dec. 15, 1976	April 6, 1977	917,820	5.69	April 6, 1977	May 24, 1977
Bruno, Unlined	Dec. 15, 1976	April 6, 1977	991,750	6.15	April 6, 1977	May 21, 1977
Bruno, Lined	Jan. 31, 1978[4]	March 26, 1978	454,880	5.85	March 30, 1978	May 26, 1978
Bruno, Unlined	Jan. 31, 1978[4]	March 26, 1978	449,080	5.78	March 30, 1978	May 25, 1978
Blucher, Lined	Dec. 5, 1972	March 16, 1973	559,920	3.85	March 5, 1973	June 11, 1973
Blucher, Unlined	Dec. 7, 1972	March 3, 1973	426,060	3.44	March 8, 1973	June 11, 1973
Blucher, Lined	Dec. 3, 1973	April 2, 1974	929,100	5.42	April 3, 1974	June 22, 1974
Blucher, Unlined	Dec. 3, 1973	April 2, 1974	954,350	5.57	April 2, 1974	June 25, 1974
Blucher, Lined	Dec. 24, 1974	April 9, 1975	1,031,740	6.76	April 12, 1975	June 6, 1975
Blucher, Unlined	Dec. 24, 1974	April 9, 1975	1,031,840	6.76	April 12, 1975	June 6, 1975
Blucher, Lined	Dec. 9, 1975	March 25, 1976	1,013,970	6.58	March 25, 1976	June 3, 1976
Blucher, Unlined	Dec. 9, 1975	March 25, 1976	1,044,840	6.78	March 25, 1976	May 25, 1976
Blucher, Lined	Dec. 10, 1976	April 6, 1977	829,240	4.92	April 6, 1977	May 26, 1977
Blucher, Unlined	Dec. 10, 1976	April 6, 1977	875,460	5.20	April 6, 1977	May 21, 1977
Blucher, Lined	Dec. 19, 1977	March 27, 1978	619,290	4.39	March 27, 1978	May 30, 1978
Blucher, Unlined	Dec. 19, 1977	March 27, 1978	670,600	4.75	March 30, 1978	June 5, 1978
Blucher, Multiple	Dec. 19, 1977	March 27, 1978	3,709,710	26.25[5]	March 30, 1978	May 15, 1978
Blucher, Lined	Dec. 21, 1978	April 9, 1979	796,060	5.07	March 20, 1979	June 28, 1979
Blucher, Unlined	Dec. 21, 1978	April 9, 1979	822,040	5.24	March 20, 1979	June 28, 1979
Blucher, Multiple	Dec. 21, 1978	April 9, 1979	4,402,530	28.05[6]	March 20, 1979	June 26, 1979
Blucher, Lined	Dec. 27, 1979	March 23, 1980	705,600	5.63	March 29, 1980	June 2, 1980
Blucher, Unlined	Dec. 27, 1979	March 23, 1980	657,876	5.25	March 29, 1980	May 21, 1980
Blucher, Multiple	Dec. 27, 1979	March 28, 1980	3,780,830	28.54[7]	March 29, 1980	May 30, 1980
Blucher, Lined	Dec. 17, 1980	April 1, 1981	691,470	4.57	March 10, 1981	June 1, 1981
Blucher, Unlined	Jan. 5, 1981	April 1, 1981	577,260	4.66	March 10, 1981	May 20, 1981
Blucher, Multiple	Dec. 17, 1980	April 1, 1981	3,393,050	22.44[8]	March 10, 1981	June 1, 1981
Armley, Lined	Dec. 5, 1973	April 8, 1974	1,149,500	6.44	April 9, 1974	July 2, 1974
Armley, Unlined	Dec. 5, 1973	April 8, 1974	1,043,60	5.84	April 9, 1974	June 27, 1974
Armley, Lined	Dec. 12, 1974	April 9, 1975	1,[illegible],010	6.83	April 10, 1975	June 25, 1975
Armley, Unlined	Dec. 12, 1974	April 9, 1975	1,160,600		April 10, 1975	June 25, 1975
Armley, Lined	Dec. 3, 1975	March 26, 1976	1,295,380	7.[illegible]	March 26, 1976	June 7, 1976
Armley, Unlined	Dec. 3, 1975	March 26, 1976	1,2[illegible]6,680	7.59	March 26, 1976	June 7, 1976
Armley, Lined	Dec. 14, 1976	April 3, 1977	919,450	5.80	April 5, 1977	May 11, 1977
Armley, Unlined	Dec. 14, 1976	April 3, 1977	953,790	6.02	April 5, 1977	May 19, 1977

TABLE 2 (Continued)

Site	Spraying Started	Spraying Stopped	Total Input Imp. Gal.	Average Input Rate Imp. Gal. per Min.	Date of First Melt Collection	Date of Completion of Melting
Ainsley, Lined	Dec. 14, 1977	March 29, 1978	720,770	4.77	April 3, 1978	June 14, 1978
Ainsley, Unlined	Dec. 14, 1977	March 29, 1978	730,890	4.83	March 31, 1978	June 14, 1978
Frontier, Lined	Dec. 12, 1973	March 24, 1974	354,530	2.41[5]	March 30, 1974	May 14, 1974
Frontier, Unlined	Dec. 12, 1973	March 24, 1974	356,770	2.43[5]	March 30, 1974	May 14, 1974
Frontier, Lined	Jan. 27, 1975	March 18, 1975	235,290	3.27[5]	March 20, 1975	May 5, 1975
Frontier, Unlined	Jan. 24, 1975	March 18, 1975	273,790	3.59[5]	March 19, 1975	May 20, 1975
Frontier, Multiple	Jan. 28, 1975	March 18, 1975	1,198,040	16.98[5 10]	March 20, 1975	May 27, 1975
Frontier, Lined	Dec. 11, 1975	March 17, 1976	413,280	2.96[5]	March 20, 1976	May 6, 1976
Frontier, Unlined	Dec. 11, 1975	March 17, 1976	434,720	3.11[5]	March 20, 1976	May 11, 1976
Frontier, Multiple	Dec. 11, 1975	March 17, 1976	2,191,580	15.69[5 11]	March 21, 1976	May 14, 1976
Frontier, Lined	Dec. 20, 1976	March 9, 1977	302,760	2.24[5]	March 24, 1977	May 8, 1977
Frontier, Unlined	Dec. 20, 1976	March 7, 1977	320,400	2.37[5]	March 24, 1977	May 8, 1977
Frontier, Multiple	Dec. 20, 1976	March 7, 1977	1,494,566	11.04[5 12]	March 24, 1977	May 9, 1977
Frontier, Lined	Dec. 21, 1977	March 23, 1978	554,200	4.18	March 23, 1978	May 22, 1978
Frontier, Unlined	Dec. 21, 1977	March 23, 1978	594,690	4.49	March 23, 1978	June 3, 1978
Frontier, Multiple	Dec. 21, 1977	March 23, 1978	2,741,216	20.69[13]	March 23, 1978	June 18, 1978
Frontier, Lined	Dec. 15, 1978	March 7, 1979	526,030	4.45	March 12, 1979	June 20, 1979
Frontier, Unlined	Dec. 15, 1978	March 7, 1979	568,560	4.82	March 12, 1979	June 22, 1979
Frontier, Multiple	Dec. 15, 1978	March 7, 1979	2,646,130	22.41[14]	March 12, 1979	June 28, 1979
Frontier, Lined	Jan. 4, 1980	March 12, 1980	342,360	3.50[5]	March 25, 1980	May 16, 1980
Frontier, Unlined	Jan. 5, 1980	March 12, 1980	381,080	3.95[5]	March 25, 1980	May 8, 1980
Frontier, Multiple	Jan. 4, 1980	March 12, 1980	1,899,620	19.40[5 15]	March 25, 1980	May 29, 1980

1 Many interruptions due to frozen lines
2 Many shutdowns, actual spraying rate closer to 4.0 gpm
3 There was an underground leak, hence actual flow rate less than 3.84 gpm
4 Late start because of well problems
5 Five spray heads; average flow 5.3 gpm per head
6 Five spray heads; average flow 5.61 gpm per head
7 Five spray heads; average flow 5.71 gpm per head
8 Five spray heads, average flow 4.49 gpm per head
9 Many shutdowns during warm weather (chinook conditions)
10 Five spray heads; average flow 3.40 gpm per head
11 Five spray heads; average flow 3.14 gpm per head
12 Five spray heads; average flow 2.21 gpm per head
13 Five spray heads; average flow 4.14 gpm per head
14 Five spray heads; average flow 4.48 gpm per head
15 Five spray heads; average flow 3.89 gpm per head

RESULTS

Meteorological data are presented in Table A-1 in the Appendix. Information extracted from the records of the Saskatchewan Research Council Climatological Station at Saskatoon are included for comparison purposes. Wind measurements are taken at the Climatological Station at ten metres above ground level so they are not directly comparable to those taken at Blucher at about one metre above ground level.

Two thermistors were installed on February 11 and readings were taken February 12 and March 9. Temperatures measured were -1.1°C and 6.1°C for thermistors 1 and 2 on February 12 and -3.3°C and -1.1°C for thermistors 1 and 2 on March 9. Because of the very mild winter and spring thermistors were partially exposed much of the time and measurements would not have been meaningful.

Melting period data are given in Tables A-2, A-3 and A-4 in the Appendix. These data are used to calculate the quantity and quality of recovered water. The best quality water is usually produced when melting is nearly completed so yields are calculated by beginning with the last sampling period and adding the preceding periods to obtain cumulative quantity (increasing) and quality (decreasing). The fraction of input recovered as product for any water quality can be determined from the calculated results. Calculated results are given in Tables 3, 4 and 5 and plotted in Figures 1, 2 and 3.

Melting rates for the three spray areas have been calculated from the data of Tables A-2, A-3 and A-4. These rates can be used to estimate the pump capacity required to transfer the melt water to storage or the injection capacity required for recharge. The melting rates are plotted in Figures 4, 5 and 6.

TABLE 3

Product Quality and Quantity, Blucher lined, 1980-81

Sample	Analysis ppm TDS	Volume Imp. Gal	Cumulative Analysis ppm TDS	Cumulative Volume Imp. Gal	% of Input Recovered
-	649*	15,300	649	15,300	2.2
BL-17	649	21,820	649	37,120	5.4
16	802	16,580	696	53,700	7.8
15	922	20,920	760	74,620	10.8
14	1,026	26,000	828	100,620	14.6
13	985	91,260	903	191,880	27.7
12	800	40,070	885	231,950	33.5
11	535	66,580	807	298,530	43.2
10	628	42,870	785	341,400	49.4
9	820	15,500	786	356,900	51.6
8	917	18,660	793	375,560	54.3
7B	658	26,970	784	402,530	58.2
7A	1,267	58,270	845	460,800	66.6
6	2,383	24,800	923	485,600	70.2
5	4,334	16,590	1,036	502,190	72.6
4	2,628	12,070	1,073	514,260	74.4
3	2,573	16,920	1,121	531,180	76.8
2	4,309	11,480	1,188	542,660	78.5
1	7,866	9,480	1,303	552,140	79.9
Input	3,316	691,470			

*Sample not analyzed; analysis assumed to be the same as that for sample BL-17.

TABLE 4

Product Quality and Quantity, Blucher Unlined 1980-81

Sample	Analysis ppm TDS	Volume Imp. Gal	Cumulative Analysis ppm TDS	Cumulative Volume Imp. Gal	% of Input Recovered
BU-16	2,408	17,590	2,408	17,590	3.0
15	2,827	24,020	2,650	41,610	7.2
14	3,104	43,120	2,881	84,730	14.7
13	3,324	22,630	2,974	107,360	18.6
12	3,708	57,970	3,232	165,330	28.0
11	3,194	41,520	3,224	206,850	35.8
10	2,246	17,650	3,147	224,500	38.9
9	2,341	20,760	3,079	245,260	42.5
8	1,748	38,140	2,900	283,400	49.1
7	1,409	60,140	2,639	343,540	59.5
6	2,698	26,820	2,643	370,360	64.2
5	4,290	35,470	2,787	405,830	70.3
4	2,841	37,610	2,792	443,440	76.8
3	4,017	37,250	2,887	480,690	83.3
2	4,710	19,560	2,958	500,250	86.7
1	15,172	1,480	2,994	501,730	86.9
Input	3,316	577,260			

TABLE 5

Product Quality and Quantity, Blucher Multiple 1980-81

Sample	Analysis ppm TDS	Volume Imp. Gal	Cumulative Analysis ppm TDS	Cumulative Volume Imp. Gal	% of Input Recovered
-	557*	67,130	557	67,130	2.0
BM-18	557	140,680	557	207,810	6.1
17	820	102,120	644	309,930	9.1
16	895	130,020	718	439,950	13.0
15	996	71,120	757	511,670	15.1
14	977	86,790	789	598,460	17.6
13	1,140	345,620	918	944,080	27.8
12	1,404	158,850	988	1,102,930	32.5
11	1,299	155,340	1,026	1,258,270	37.1
10	1,130	400,630	1,051	1,658,900	48.9
9	2,014	122,190	1,117	1,781,090	52.5
8	1,780	108,630	1,155	1,889,720	55.7
7	1,297	293,320	1,174	2,183,040	64.3
6	2,421	207,300	1,282	2,390,340	70.4
5	3,447	123,700	1,389	2,514,040	74.1
4	4,975	70,700	1,487	2,584,740	76.2
3	5,894	97,000	1,646	2,681,740	79.0
2	5,270	90,300	1,765	2,772,040	81.7
1	6,433	49,500	1,946	2,821,540	83.2
Input	3,316	3,393,050			

*Sample not analyzed; analysis assumed to be the same as that for sample BM-18

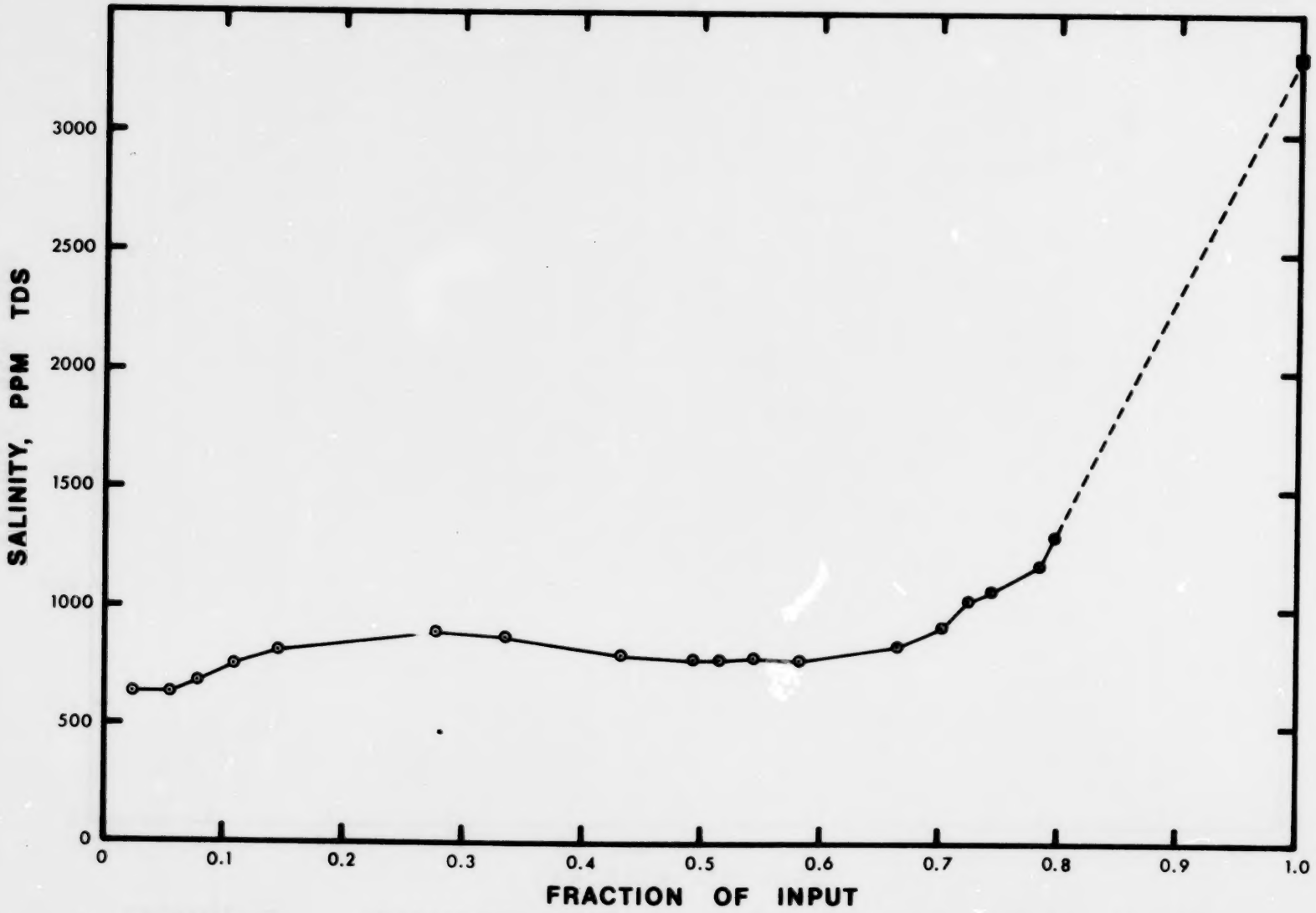

FIGURE 1. QUANTITY AND QUALITY OF RECOVERED WATER, BLUCHER LINED

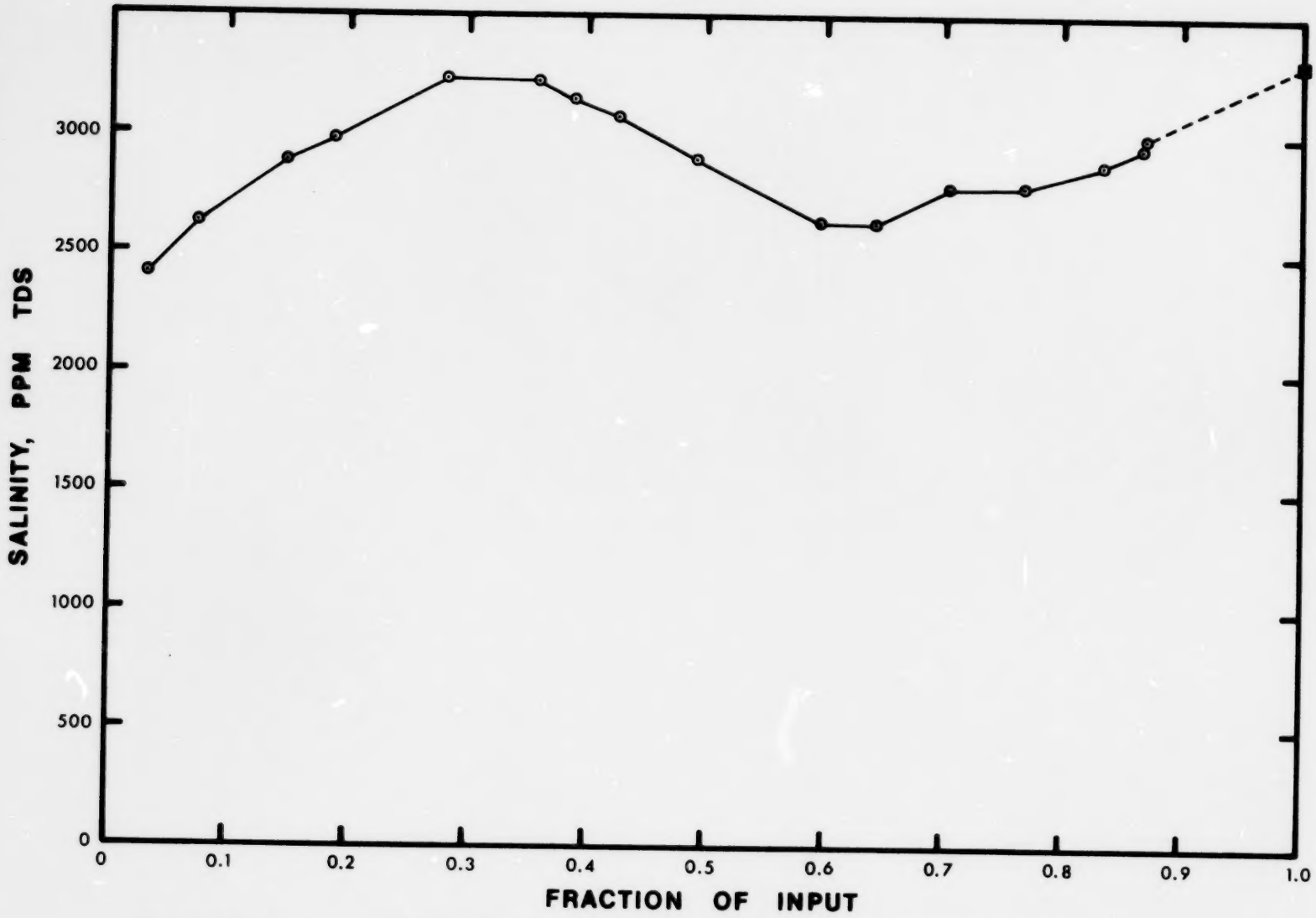

FIGURE 2. QUANTITY AND QUALITY OF RECOVERED WATER, BLUCHER UNLINED

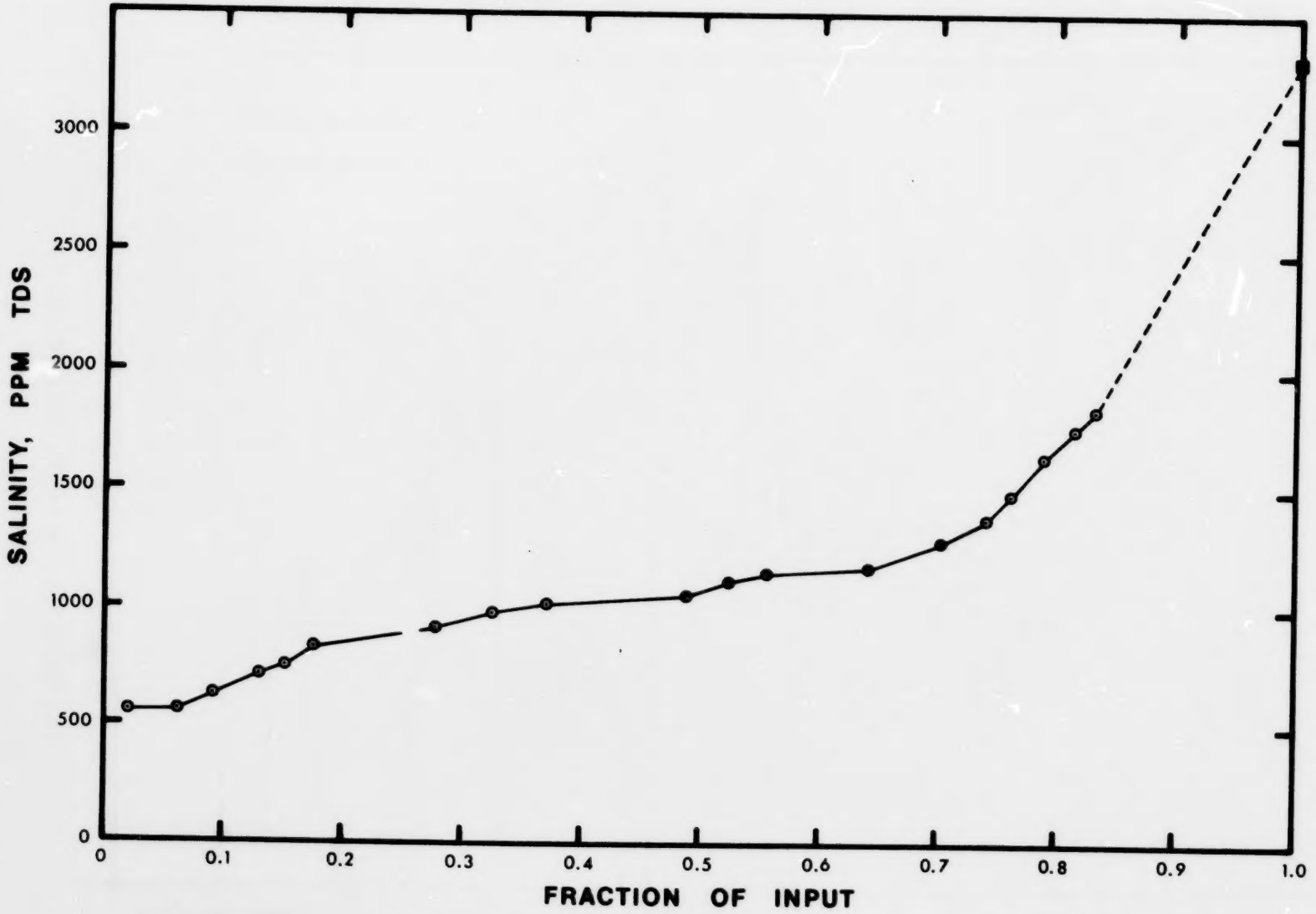

FIGURE 3. QUANTITY AND QUALITY OF RECOVERED WATER, BLUCHER MULTIPLE

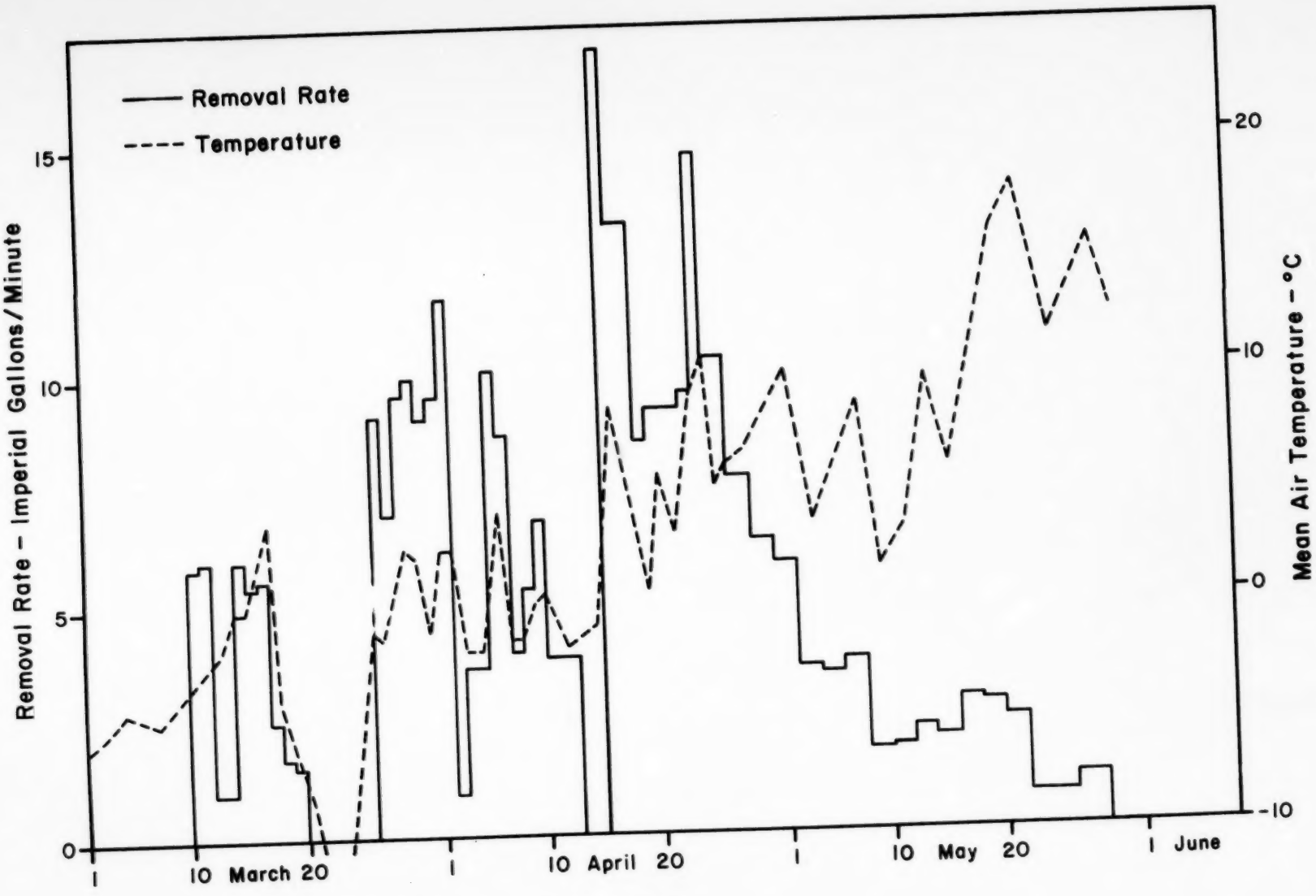

FIG. 4 MELTING RATES, BLUCHER LINED

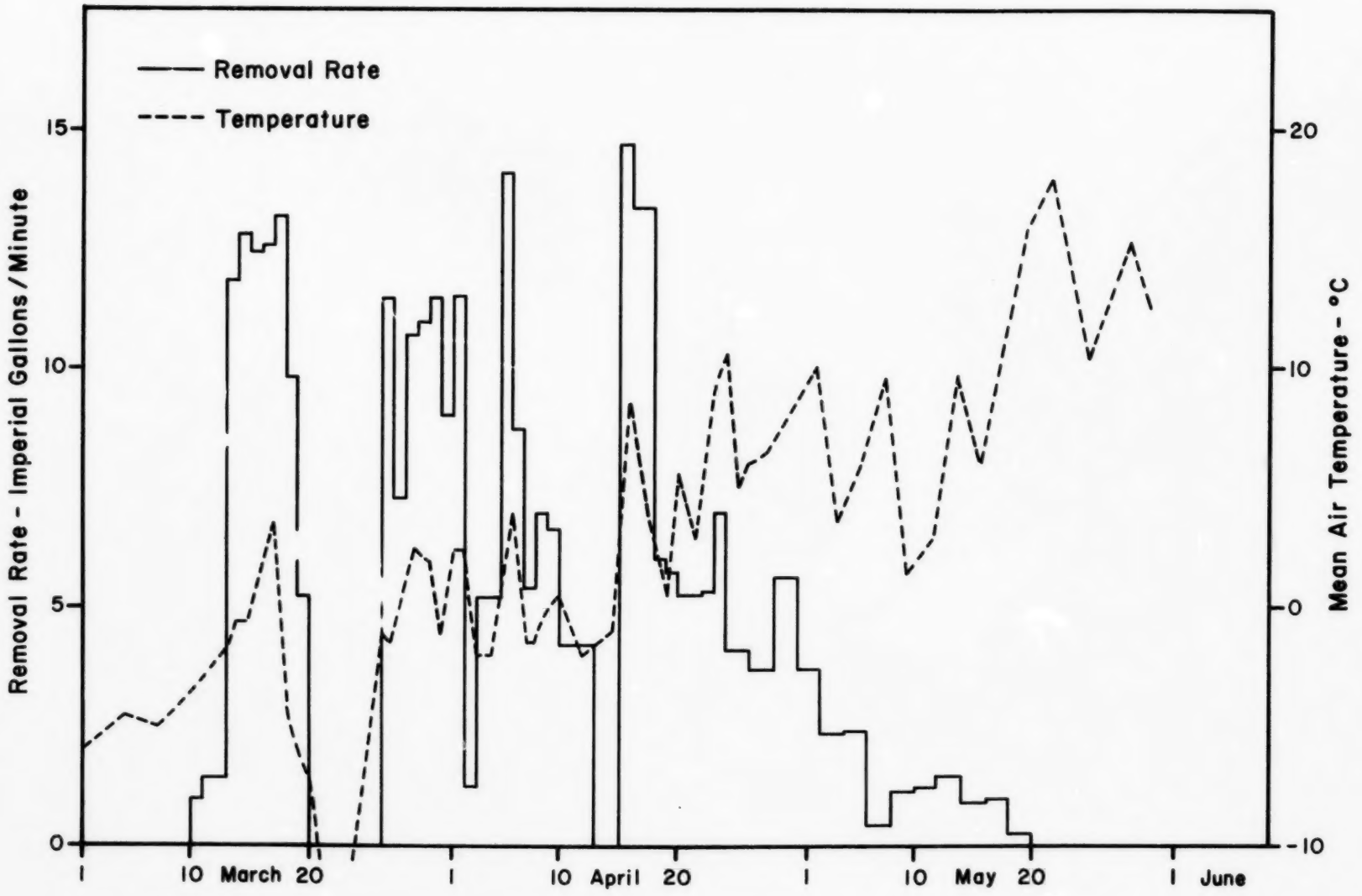

FIG.5 MELTING RATES, BLUCHER UNLINED

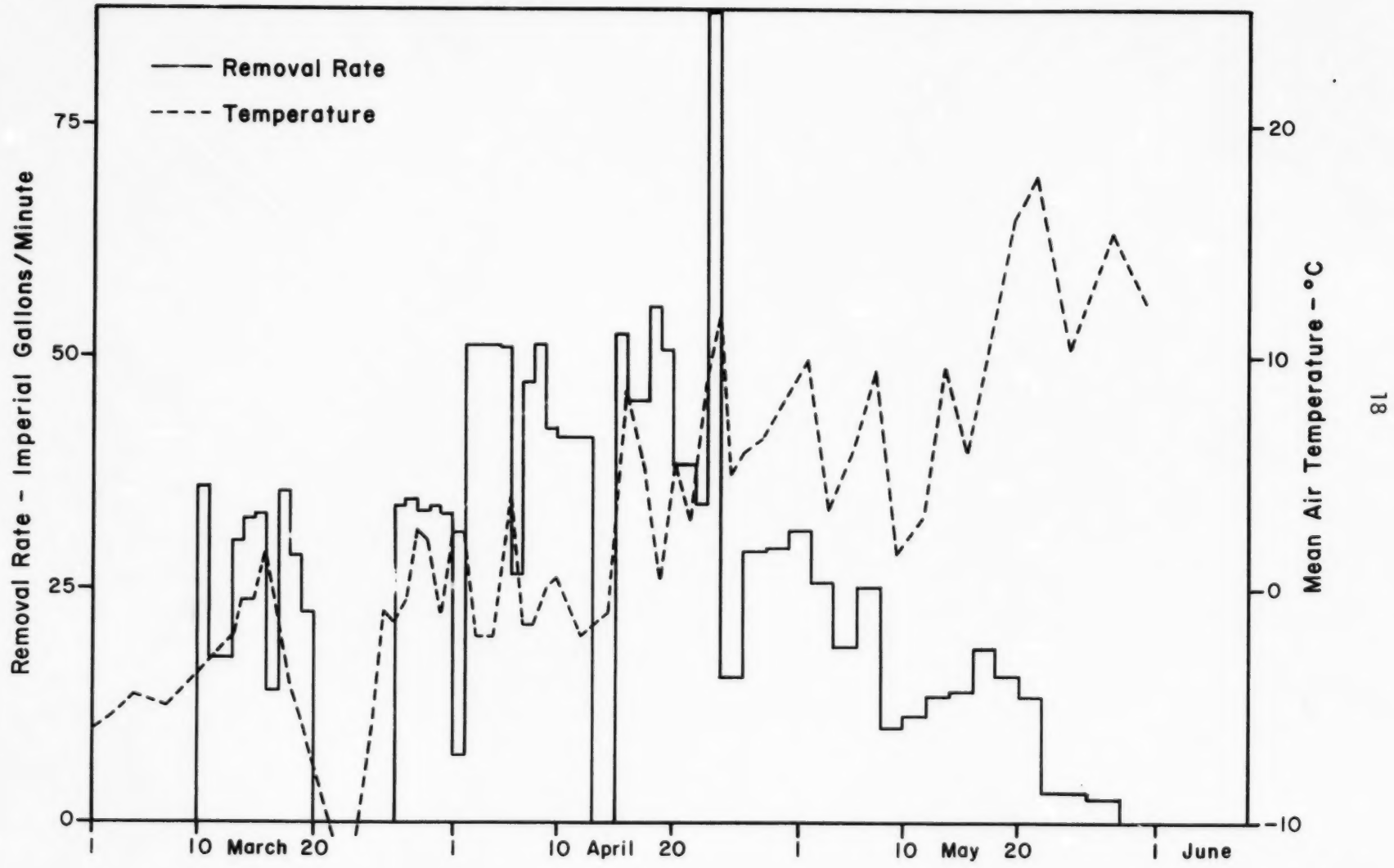

FIG. 6 MELTING RATES, BLUCHER MULTIPLE

DISCUSSION OF SPRAY FREEZING RESULTS AND CONCLUSIONS

Freeze desalination works because when a solution of inorganic salts is cooled to the freezing point, essentially pure ice forms and the salts concentrate in the remaining liquid. Further cooling produces more pure ice and a more concentrated solution. There is a temperature-concentration equilibrium for any particular dissolved solids composition. Further cooling eventually leads to complete solidification. This occurs at the eutectic temperature. The value of the eutectic temperature is determined by the salt composition. Sometimes solubility limits are exceeded and salts or salt hydrates are precipitated at temperatures above the eutectic. For example, sodium sulphate decahydrate can coexist with ice and solution for some compositions in the sodium magnesium chloride sulphate water system.

To obtain desalinated water, the ice must be separated from the salts, therefore the salts must remain in solution. This means that the temperature must remain above the eutectic. Preferably the temperature should remain high enough so that solubility limits will not be exceeded either, but small quantities of precipitated salts will not seriously contaminate the product. In ice mounds produced by spray freezing, brine can drain to the bottom of the mound because its density is higher than that of ice. Some brine will remain in the ice because it is trapped in pockets isolated from the main drainage network and some will adhere to the ice crystal surfaces. Part of this retained brine will be flushed from the ice mound in the spring by melt water percolating through it.

If the ice mound cools below the eutectic temperature, re-establishment of a drainage network is very difficult. This is because the thermal gradient for warming the interior is the temperature difference between the surface and the interior of the ice, and the surface temperature can never exceed the melting point of ice. Hence, not much internal warming can occur under the time restraints imposed by the natural melting regime.

During the freezing period ice mound temperatures are kept above the eutectic temperature by adjusting the spraying rates so that heat losses to the atmosphere are offset by the latent heat given up by freezing most of the water which is sprayed. The sprayed water should be distributed as evenly as possible in order to prevent development of local cold spots. Spray heads have been developed which are satisfactory most of the time but cannot provide even distribution under extreme weather conditions (high wind chill). Wind disturbs the water distribution patterns and irregularities form on the ice surface. Once irregularities form they usually continue to grow after normal spraying patterns have been re-established and ledges, spires, icicles and ice caves can form. These usually will be below the eutectic temperature because they have a high surface to volume ratio.

Continued modification of spray head design and the use of different types of spray heads for different weather conditions and pre-existing ice shapes have improved the overall mound shapes, but have not eliminated all of the problems associated with extreme weather conditions. Higher spraying rates might improve the situation but our rates are limited by the capacities of the existing wells and distribution systems. A discussion of the present state-of-the-art in sprinkler design was included

in Appendix B in last year's report (13).

All of the natural freezing experiments conducted by the council have shown that solutions containing univalent ions such as sodium, chloride and bicarbonate are easier to desalinate than solutions of divalent ions such as magnesium, calcium and sulphate. This is at least partially due to the difference in eutectic temperatures; lower eutectic temperatures allow more latitude for maintaining the temperature above the eutectic. Eutectic temperatures have been discussed previously (7). For the salts normally found in Saskatchewan groundwater the eutectic temperatures for water-single salt systems are $NaCl-H_2O$ -21.2°C, Na_2CO_3 - H_2O -2.1°C, Na_2SO_4 - H_2O -1.2°C, $MgSO_4$ - H_2O -3.9°C, $MgCl_2$ - H_2O -33.6°C and $CaCl_2$ - H_2O -51.0°C. For water-multiple salt systems the eutectic temperature is usually lower than for water-single salt systems, for example, for the NaCl - Na_2SO_4 - H_2O system it is -21.7°C and for the Na_2SO_4 - $MgSO_4$ - H_2O system it is -5.0°C.

Product yields for any quality level can be determined from Tables 3, 4 and 5 or Figures 1, 2 or 3. Some yields are compared to those for previous years in Table 6. The year to year differences are discussed below.

The lined and unlined units at Blucher have been operated for nine years and the multiple unit for four years. It should be remembered that the unlined unit was fitted with a polyethylene liner this year. Overall recoveries were 79.9, 86.9 and 83.2 percent for the lined, unlined and multiple units. These are quite high, but are only average when compared to previous results from Blucher. Over the nine years of operation the average recoveries were 88.6 and 84.4 for the lined and unlined units and

Table 6

Yields as Percentage of Input for Various Product Salinities

Site	Season	Initial Salinity ppm TDS	Total Yield	Yield at a Product Salinity of				
				500 ppm	1,000 ppm	1,500 ppm	2,000 ppm	½ Initial salinity
Outdoor Laboratory Lined	1970-71	1,999	98.8%	77.6%	86.4%	92.1%	98.5%	86.4
Outdoor Laboratory Lined	1971-72	4,506	102.9	39.8	84.8	91.0	95.8	97.2
Outdoor Laboratory Lined	1972-73	3,187[1]	101.9	17.5	29.6	46.1	88.8	56.8
Outdoor Laboratory Lined	1973-74	3,343	88.9	37.1	88.5	88.9	88.9	88.9
Outdoor Laboratory Lined	1974-75	2,697	64.9	40.8	64.9	64.9	64.9	64.9
Outdoor Laboratory Lined	1975-76	2,885	62.8	62.3	62.8	62.8	62.8	62.8
Outdoor Laboratory Lined	1976-77	2,875	53.2	29.9	53.2	53.2	53.2	53.2
Outdoor Laboratory Lined	1977-78	2,899	73.2	53.3	73.2	73.2	73.2	73.2
Outdoor Laboratory Lined	1978-79	3,044	78.2	61.6	74.8	78.2	78.2	78.2
Outdoor Laboratory Lined	1979-80	3,007	78.6	75.4	78.6	78.6	78.6	78.6
Bruno Lined	1972-73	2,460	82.5	9.5	32.5	82.5	82.5	69.3
Bruno Lined	1973-74	2,435	78.3	1.1	15.9	78.3	78.3	32.2
Bruno Lined	1974-75	2,462	76.8	10.7	30.7	76.8	76.8	60.5
Bruno Lined	1975-76	2,461	83.4	0	19.2	83.4	83.4	35.8
Bruno Lined	1976-77	2,497	78.4	0	21.9	78.4	78.4	31.2
Bruno Lined	1977-78	2,616	97.5	0.6	64.8	88.7	97.5	80.8
Bruno Unlined	1972-73	2,462	58.1	6.3	56.4	58.1	58.1	58.1
Bruno Unlined	1973-74	2,435	83.0	0	3.1	83.0	83.0	83.0
Bruno Unlined	1974-75	2,462	69.9	0	0	69.9	69.9	23.9
Bruno Unlined	1975-76	2,461	74.4	0	0	74.4	74.4	0
Bruno Unlined	1976-77	2,497	65.2	0	0	65.2	65.2	0
Bruno Unlined	1977-78	2,616	84.2	0	0	81.6	84.2	71.3
Blucher Lined	1972-73	3,346	99.0	10.7	30.7	56.6	86.0	66.0
Blucher Lined	1973-74	3,314	83.2	3.8	18.5	80.6	83.3	82.2
Blucher Lined	1974-75	3,245	82.6	0	0	79.7	82.6	81.4
Blucher Lined	1975-76	3,268	82.0	0	0	80.6	82.0	81.1
Blucher Lined	1976-77	3,244	79.3	0	0	75.8	79.3	78.0
Blucher Lined	1977-78	3,494	97.1	0	6.2	26.1	82.2	42.8
Blucher Lined	1978-79	3,275	100.4	0	0	38.0	92.2	44.7
Blucher Lined	1979-80	3,322	93.6	0	0	15.6	93.6	20.3
Blucher Lined	1980-81	3,316	79.9	0	71.8	79.9	79.9	79.9
Blucher Unlined	1972-73	3,346	71.8	0	0	38.0	58.3	46.9
Blucher Unlined	1973-74	3,314	86.9	0	0	15.3	86.9	23.5
Blucher Unlined	1974-75	3,245	64.8	0	0	0	64.8	32.1
Blucher Unlined	1975-76	3,268	73.7	0	0	0	17.7	0
Blucher Unlined	1976-77	3,244	82.1	0	0	22.0	41.6	26.2
Blucher Unlined	1977-78	3,494	97.3	0	0	0	0	0
Blucher Unlined	1978-79	3,275	102.7	0	0	0	0	0
Blucher Unlined	1979-80	3,322	93.6	0	0	0	0	0
Blucher Unlined	1980-81	3,316	86.9	0	0	0	0	0
Blucher Multiple	1977-78	3,494	61.3	0	0	0	0	0
Blucher Multiple	1978-79	3,275	97.2	0	0	9.8	54.9	15.4
Blucher Multiple	1979-80	3,322	92.5	0	0	7.2	88.0	44.7
Blucher Multiple	1980-81	3,316	83.2	0	32.8	76.4	83.2	79.3
Armley Lined	1973-74	4,122	83.3	20.3	80.2	82.3	83.3	83.3
Armley Lined	1974-75	4,194	74.2	24.2	63.6	67.2	71.0	71.1
Armley Lined	1975-76	4,129	70.4	0[3]	46.1	60.3	63.7	64.2
Armley Lined	1976-77	4,169	64.5	0	0	59.5	62.2	62.7
Armley Lined	1977-78	4,142	95.6	0	78.1	82.3	85.3	85.8
Armley Unlined	1973-74	4,122	73.0	5.1	54.1	71.6	73.0	73.0
Armley Unlined	1974-75	4,194	41.6[2]	0	31.5	40.4	41.6	41.6
Armley Unlined	1975-76	4,129	56.4	0	38.3	[illegible]	56.4	56.4
Armley Unlined	1976-77	4,169	66.2	0	61.2	[illegible]	66.2	66.2
Armley Unlined	1977-78	4,142	93.7	0	0	82.2	87.8	88.5
Frontier Lined	1973-74	1,823	91.9	84.4	91.9	91.9	91.9	91.9
Frontier Lined	1974-75	1,855	105.2	90.2	[illegible]	105.2	105.2	99.9
Frontier Lined	1975-76	1,858	83.6	[illegible]	[illegible]	83.6	83.6	83.6
Frontier Lined	1976-77	1,888	85.1	63.1	[illegible]	85.1	85.1	83.4
Frontier Lined	1977-78	1,871	102.4	95.6	102.4	102.4	102.4	102.4
Frontier Lined	1978-79	1,860	88.4	77.9	88.4	88.4	88.4	88.4
Frontier Lined	1979-80	1,790	82.4	73.5	82.4	82.4	82.4	82.4
Frontier Unlined	1973-74	1,823	75.3	75.3	75.3	75.3	75.3	75.3
Frontier Unlined	1974-75	1,855	95.2	92.	95.2	95.2	95.2	95.2
Frontier Unlined	1975-76	1,858	75.2	75.2	75.2	75.2	75.2	75.2
Frontier Unlined	1976-77	1,888	[illegible]	67.7	67.7	67.7	67.7	67.7
Frontier Unlined	1977-78	1,871	93.5	88.4	93.5	93.5	93.5	93.5
Frontier Unlined	1978-79	1,860	88.3	86.2	88.3	88.3	88.3	88.3
Frontier Unlined	1979-80	1,790	73.8	73.4	73.8	73.8	73.8	73.8
Frontier Multiple	1974-75	1,855	73.1	73.1	73.1	73.1	73.1	73.1
Frontier Multiple	1975-76	1,858	57.6	57.6	57.6	57.6	57.6	57.6
Frontier Multiple	1976-77	1,888	60.6	60.6	60.6	60.6	60.6	60.6
Frontier Multiple	1977-78	1,871	87.4	71.4	87.4	87.4	87.4	87.4
Frontier Multiple	1978-79	1,860	81.6	0	81.6	81.6	81.6	81.6
Frontier Multiple	1979-80	1,790	71.3	0[4]	71.3	71.3	71.3	71.3

[1] Added salt was sodium sulphate; in all other years the added salt at the outdoor laboratory was sodium chloride.

[2] Losses were high because of leak through dike surrounding the spray area.

[3] 24.5% less than 550 ppm.

[4] 57.7% less than 550 ppm.

over four years 83.6 for the multiple unit. For the three seasons 1978-79, 1979-80 and 1980-81, the average recoveries were 91.3, 94.4 and 91.0 for the lined, unlined and multiple units.

As stated above, the apparent recovery from the unlined unit was 86.9 percent, the highest of the three units this year. This high recovery may be because the polyethylene liner was in place. All of the water recovered had a rather high salinity; only two of the samples contained less than 2000 ppm TDS. However, the final samples did not have a very high salinity as had occurred in previous years. The reason for this different salinity distribution is not immediately apparent. The following hypothesis might explain it. In previous years, particularly when apparent recoveries were high, high salinities in the recovered water were attributed to re-solution of salts from the base of the spray basin augmented by groundwater discharge. This year a liner was in place and groundwater appeared to be lower (lower recovery). However, the liner was in sections which were overlapped but not sealed. Equilibrium with the soil moisture at the base of the spraying area, with little or no groundwater discharge, could explain the high, relatively constant salinity of the recovered water.

The above hypothesis is in general agreement with the groundwater discharge hypothesis proposed in previous years. In 1979 when apparent recovery exceeded 100 percent, the product water had a salt content, on average, exceeding the salt content of the input water. In 1980 the apparent recovery was lower suggesting reduced groundwater discharge to the spraying area; the product water quality was better than in 1979. In 1981, the apparent recovery was slightly lower than in 1980; the water quality was about the same for 1980 and 1981 at the 70 percent recovery level.

The polyethylene liner may have caused a slightly higher overall recovery, but did not appear to have much effect on product quality. A polyethylene liner installed without joining seams and without cover material would have to be replaced annually. The cost could not be justified, at least for the soil conditions which are present at Blucher.

The problems associated with salt buildup in the base of spray freezing basins show that care is required when choosing a site. If a site with a deep water table and permeable base material is chosen, product quality would not deteriorate from year to year, but seepage losses might be unacceptably high. Conversely, if a site with relatively impermeable base material and/or a high water table is chosen, yield would be higher but quality would probably decrease as salts accumulated in the base material. An intermediate situation with only enough seepage to clear the salts from the base of the spray area would be best. Of course, potential groundwater contamination must also be considered when a site is being selected.

The lined unit had a recovery of only 79.9 percent, but the quality was very good; all of the product contained less than 1500 ppm TDS and over 70 percent of the input was recovered as product containing less than 1000 ppm TDS. This was the best quality achieved during the nine years this unit has been operated. This is a satisfying result, but why it was achieved is not clear-cut, especially as most of the operating conditions were the same as for the unlined unit, the results from which were not nearly as good.

The reasons for the high quality could include:

1. Reduced re-solution of salts from the base of the spraying area due to lowered water table. There is obviously some leakage through the liner and hence contact with the base since only 79.9 percent of the input was recovered.

2. Warmer weather during the spraying season (see discussion on weather later in this section).

3. Better ice shape and therfore higher ice temperatures resulting from improved understanding of spray head requirements.

These reasons would apply to the unlined unit also, however over the years more salt has entered the soil beneath the unlined unit and re-solution may mask the above beneficial effects. Masking may have been enhanced by having a liner in place for one year; reduced seepage from the ice pile would result in less flushing of the salts in the base.

For the multiple unit recovery was 83.2 percent, lower than in the previous two years, but purification efficiency was improved. All of the recovered water contained less than 2000 ppm TDS and about 75 percent of the input was recovered as water containing less than 1500 ppm TDS. This was not quite as good as the lined unit, but much better than the unlined one. It is quite possible that as the base of the multiple spray area becomes contaminated with brine seepage, the purification efficiency may deteriorate as has been the case for the unlined unit.

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Weather data from Table A-1 are summarized in Table 7. For January, February and March, the freezing season, temperatures were considerably higher and winds were slightly lower in 1981 than in 1980. For April and May, the melting season, temperatures were slightly lower and winds were slightly higher in 1981.

Overall, the temperature during the 1980-81 spraying season was the highest experienced since spray freezing began. The average temperatures over the nine year period are summarized in Table 8.

The 1980-81 results are better than in some previous years but the purification efficiency is still relatively low compared to results obtained at the outdoor laboratory and at Frontier in other years. This confirms the observations made in previous reports that the type of salt dissolved in the water has a great effect on purification efficiency. Much higher purification efficiencies were obtained from the chloride and bicarbonate waters at the outdoor laboratory and at Frontier than from the sulphate water at Blucher.

Table 9 shows the fractions of each of the ions and of total dissolved solids recovered from the three units. Salt recoveries were generally lower than water recoveries. In previous reports (6), (7), (8), (9), (10), (11), (12), (13) this was attributed to differential seepage losses of winter brine drainage and initial spring drainage. More of the initial drainage will be lost as seepage because as melting continues the soil will become wetter and a smaller fraction of the more dilute melt water will seep away. A similar effect can occur in lined areas if there is liner damage which allows seepage to occur. This hypothesis can be justified even if recoveries are high. If seepage of

TABLE 7

Summary of Weather Data During 1980-81 Season

Period	Blucher		SRC Climatological Station	
	Avg. Temp. °C	Avg. Wind kmph	Avg. Temp. °C	Avg. Wind kmph
Dec. 1980 (partial)	-20.3	12.6	-17.4	11.2
Jan. 1981	-14.9	13.2	-10.4	10.8
Feb. 1981	-13.6	11.5	-10.2	12.8
March 1981	- 4.3	10.9	- 1.2	11.3
April 1981	+ 2.3	14.0	+ 5.4	15.8
May 1981	+ 9.7	14.3	+12.5	15.7

TABLE 8

Yearly Temperature Averages For the Months of January, February and March

Year	Site						
	Outdoor Laboratory	Bruno	Blucher	Armley	Frontier	Average of all Sites	Average of Outdoor Laboratory Blucher and Frontier
1973	- 9.5°C	-11.5°C	-10.8°C			-10.6°C[4]	-10.2°C[5]
1974	-16.3	-17.7	-19.0[1]	-20.2°C	- 7.0°C	-16.0	-14.1
1975	-15.2	-15.1	-17.2	-17.5	-10.4[2]	-15.1	-14.3
1976	-11.1	-12.9	-13.1	-15.0	- 6.4	-11.7	-10.2
1977	- 9.6	-11.9	-13.0	-14.8	- 6.7	-11.2	- 9.8
1978	-14.8	-12.7[3]	-16.7	-17.9	-13.7	-15.2	-15.1
1979	-17.7	-	-20.2	-	-14.2	-	-17.4
1980	-14.1	-	-16.6	-	-11.2	-	-14.0
1981	- 7.2	-	-10.8	-	-	-	- 9.0[5]

[1] January and February only.

[2] January 1 to 21 not included.

[3] February and March only.

[4] Outdoor Laboratory, Blucher and Bruno only.

[5] Outdoor Laboratory and Blucher only.

TABLE 9

Recovery of Salts and Water at Blucher

Component	Lined			Unlined			Multiple		
	Input ppm	Output ppm	Fraction Recovered	Input ppm	Output ppm	Fraction Recovered	Input ppm	Output ppm	Fraction Recovered
Calcium	1'3	96.0	0.419	183	131.9	0.626	183	108.7	0.494
Magnesium	.8	25.1	0.418	48	110.5	2.000	48	36.7	0.636
Sodium	817	291.1	0.285	817	670.7	0.713	817	415.8	0.423
Potassium	7.8	4.0	0.410	7.8	8.4	0.936	7.8	6.0	0.640
Iron	20	0.50*	0.020	20	0.71**	0.031	20	0.28***	0.012
Manganese	1.'	0.14*	0.102	1.1	0.47**	0.371	1.1	0.18***	0.136
Carbonate	0	0	-	0	0	-	0	0	-
Bicarbonate	480	155 8	0.259	480	286.6	0.519	480	186.1	0.323
Chloride	349	15.6	0.265	349	347.0	0.864	349	167.5	0.399
Sulphate	1410	25.0	0.354	1410	1437.8	0.886	1410	928.5	0.548
Total Dissolved Solids	3316	.104	0.314	3316	2993.7	0.785	3316	1846.4	0.463
Water	691470 gal.	552140 gal.	0.799	577260 gal.	501730 gal.	0.869	3393050 gal.	2821540 gal.	0.832

* Analysis done on only 13 of 18 samples; analyses for remainder estimated by interpolation and extrapolation.

** Analysis done on only 12 of 16 samples; analyses for remainder estimated by interpolation and extrapolation.

*** Analysis done on only 12 of 19 samples; analyses for remainder estimated by interpolation and extrapolation

highly concentrated brine occurs during the winter as it drains from the ice mound followed by no seepage, or even by groundwater discharge, during the melting season, the differential seepage hypothesis is still valid.

The ratios of the fractions of the various ions recovered were similar to those of previous seasons. The relative recoveries of ions have been discussed previously (9), (10), (11), (12), (13); the conclusions reached are supported by the 1980-81 results and will be repeated here.

The fraction of bicarbonate recovered is lower than for other major ions. Bicarbonate is probably lost during spraying according to the reaction:

$$2HCO_3^- \rightarrow CO_3^{=} + CO_2 + H_2O$$

Little carbonate was found in the product water but it could have precipitated with calcium or reconversion to bicarbonate according to the equation:

$$CO_3^{=} + H^+ \rightarrow HCO_3^-$$

could possibly occur later in the season.

The fraction of sulphate recovered is again high. This indicates that sulphate is not readily removed from the ice, have a smaller fraction is lost by seepage. The fraction of chloride recovered has varied from year to year but the general trend has been toward increased recovery implying that the chloride which has seeped from the ice in previous years may be saturating the soil beneath the spraying areas.

PHYSIOLOGICAL EFFECTS OF BRACKISH WATERS

Three papers obtained this year are not strictly concerned with physiological effects, but are summarized under this heading because they deal with human perception of water quality. A paper by Lauch and Sorg (14) on sodium in drinking water will be discussed in the next section as it deals primarily with economics of sodium removal.

Zoeteman, Piet and Postma (15) suggest the use of water taste assessment as a long-term water quality indicator. The article deals primarily with organic contaminants but does include some comments on the taste intensities for various inorganic constituents. "It has been generally established that the sulphates and hydrocarbonates affect taste intensity and quality less than the chlorides and carbonates. The taste threshold concentration (TTC) of 75 mg/ℓ Na_2CO_3 is about 15 times lower than the TTC of 1060 mg/ℓ $NaHCO_3$ ..... in many cases the cation seems to be more important for the taste of salt ..... than the anion ..... In recent studies the magnesium ion (as $MgCl_2$ or $Mg(HCO_3)_2$) gave distilled water an offensive taste to 50 percent of a consumer panel at a concentration of about 10 mg/ℓ Mg^{++}, while for calcium in the same salts the corresponding values were between 100 and 150 mg/ℓ Ca^{++}. The offensive concentration for sodium is approximately 200 mg/ℓ Na^{+} ..... Among the metal ions in water, iron can be tasted in distilled water by the most sensitive 5 percent of a panel at 0.05 mg/ℓ, copper at 2.5 mg/ℓ, manganese at 0.5 mg/ℓ and zinc at about 5 mg/ℓ."

Bruvold (16) investigated the attitudes of the residents of Irvine, California toward the use of reclaimed water. In that community reclaimed water was already being used to fill an ornamental lake and to irrigate

golf courses, food crops and some common lawn areas. Attitudes towards existing and additional uses for reclaimed water were assessed. Bruvold found that about 90 percent of the respondents were in favor of continuing the existing uses of reclaimed water but only 28 percent had a positive attitude toward the hypothetical use of reclaimed water for drinking purposes although 53 percent felt there was no health risk associated with the use of reclaimed water.

Bruvold and Cook (17) assessed public attitudes toward the use of reclaimed water for drinking using a quantitative measure of attitudes and assessed the relations of attitudes to sociodemographic and belief variables. The survey was made in ten California communities. "The results ..... indicate a consistent, if not strong, negativity toward the general prospect of using reclaimed water for drinking ..... The present data showed a direct relation between attitudes toward drinking water and income level, educational level and amount thought about reclaimed water with an inverse relation obtained for age of respondent and length of residence at the current address ..... In conclusion, the present results generally recommend options for wastewater treatment and reuse that stipulate advanced wastewater treatment followed by beneficial reuse not involving a high degree of human contact."

ECONOMIC CONSIDERATIONS

Lauch and Sorg (14) describe the occurrence of sodium in drinking water, both natural and introduced by man's activities and water treatment techniques and then go on to methods for removing sodium. They say "the most obvious way of reducing sodium concentration in drinking water is to reduce or eliminate sodium added during various treatment processes ..... treatment processes adding the most significant quantities of sodium are softening, disinfection and pH adjustment ..... a literature search uncovered no report on the removal of sodium, 'as a specific ion' from drinking water ..... Because no reports specifically on sodium removal were found, desalination and demineralization will be discussed in relation to sodium reduction. Processes used are ..... reverse osmosis, distillation, ion exchange, electrodialysis and blending."

With regard to reverse osmosis Lauch and Sorg report on a number of systems. In Greenfield, Iowa a system produced 600 m^3/day of water containing TDS of less than 500 mg/ℓ from raw water with a TDS concentration of 2200 mg/ℓ at a cost of 20.7 cents/m^3 in 1972 US dollars. A 12,000 m^3/day plant at Cape Coral, Florida reduced TDS from 1234 to 63 mg/ℓ and sodium from 371 to 23 mg/ℓ at a cost, exclusive of membrane replacement, of about 26.4 cents/m^3 in 1976 US dollars. Dissolved solids and sodium reductions for eight different reverse osmosis units in Sarasota County, Florida were tabulated. These data are reproduced here as Table 10.

Table 10 Total Dissolved Solids and Sodium Reduction by Eight Different Reverse Osmosis Systems in Sarasota County, Florida

System	Population	Manufacturer	Membrane	Product Water Design Capacity m^3/day	TDS - mg/ℓ		Sodium		
					Source Water	Product Water	Source Water mg/ℓ	Product Water mg/ℓ	Percentage Removed
City of Venice	15,000	Polymetrics	Hollow fiber, Dupont	3,785	2,412	129	140	25.4	82
Sorrento Shores	1,300	Permutit	Spiral wound, UOP	2,865	3,373	404	258	45	83
Spanish Lakes Mobile Home Park	340	Universal Oil Products (UOP)	Spiral wound, UOP	1,003	1,327	158	39	7.5	81
Bay Lake Estates Motor Home Park	34	Purification Techniques	Hollow fiber, Dupont	572	2,532	113	48	8.6	82
Kings Gate Trailer Park	600	Purification Techniques	Hollow fiber, Dupont	428	1,620	256	51	21.3	58
Sarasota Bay Mobile Home Park	135	Polymetrics	Hollow fiber, Dupont	72	2,430	62	38.1	9.1	76
Bay Front Trailer Park	39	Continental Water Conditioning	Hollow fiber, Dupont	23	895	66	59	13	78
Nokomis School	800	Basic Technologies	Spiral wound, Basic Technologies	11.4	1,442	109	74	10.4	86

With regard to distillation Lauch and Sorg say "Municipal desalting plants typically reduce TDS concentrations from about 34,000 mg/ℓ to a range of 100 to 500 mg/ℓ ..... The Key West Florida plant has 50 stages, requires only 1.58 J/kg of distillate and produces water for 22.7 cents/m^3 in 1969 US dollars."

All of the processes are discussed and it is shown that all will reduce sodium contents to acceptable levels. Costs are compared in a Table reproduced here as Table 11. "The table shows that ion exchange, electrodialysis and reverse osmosis are more economical than distillation. Ion exchange is used mainly for water with lower TDS concentrations (< 1000 mg/ℓ) to demineralize the water for industrial processes. Inland waters that are high in sodium could have a TDS concentration of 1000 to 5000 mg/ℓ and reverse osmosis or electrodialysis would be used to treat these waters."

Sorg (18) discusses methods of nitrate removal and concludes that "only ion exchange and reverse osmosis are considered feasible and practical for full-scale treatment of drinking water." Capital and operating costs for these two processes, together with those for ion exchange softening and activated alumina fluoride removal are presented by Sorg and are reproduced here as Tables 12 and 13. These costs reflect 1979, or possibly 1978, prices. For this analysis it is obvious that reverse osmosis is not economically competitive with ion exchange unless there are contaminants other than nitrate to be controlled.

Stevie and Clark (19) considered the general financial impact of the National Interim Drinking Water Regulation (NIDWR) on water utilities in the USA. The impact is of particular concern for small water utilities.

TABLE 11

Estimated Costs (1980) for Removal of TDS and Sodium from Drinking Water

Type of Treatment	Capacity		TDS Estimate		TDS Estimate		Estimate of Total Costs	
	m^3/day	mUSgd	Typical Source Water Concentration mg/ℓ	Percentage Removed	Typical Source Water Concentration mg/ℓ	Percentage Removed	dollars per m^3	per 1000 USg
Reverse osmosis	3,785	1	2,500	94	500	93	0.227	0.86
Electrodialysis	3,785	1	2,500	85	200	75	0.211	0.80
Ion Exchange	3,785	.	500	85-95	150	85	0.214	0.81
Distillation	3,785	1	34,000	99.7			1.59-2.64	6-10

TABLE 12

Construction Costs, Water Treatment Systems

Plant Capacity m^3/da	Ion Exchange Softening	Activated Alumina Fluoride Removal	Ion Exchange Nitrate Removal	Reverse Osmosis
189	60,500	50,000	65,000	78,000
379	68,000	58,000	74,000	131,000
946	85,000	72,000	98,000	245,000
1893	106,000	92,000	129,000	430,000
2839	131,000	110,000	170,000	625,000
3785	150,000	130,000	221,000	776,000

TABLE 13

Operation and Maintenance Costs

Yearly O & M costs, U.S. $ and (cents/m^3)

Plant Capacity m^3/day	Ion Exchange Softening	Activated Alumina Fluoride Removal	Ion Exchange Nitrate Removal	Reverse Osmosis
189	11,500 (16.6)	13,000 (18.8)	12,400 (18.0)	21,300 (30.9)
379	12,200 (8.7)	15,000 (10.8)	15,000 (10.8)	33,500 (24.3)
946	15,500 (4.5)	16,000 (4.8)	20,000 (5.8)	63,000 (18.2)
1893	19,800 (2.9)	18,000 (2.6)	26,900 (4.0)	104,000 (15.1)
2839	23,000 (2.1)	20,800 (2.1)	34,800 (3.4)	142,000 (13.7)
3785	25,300 (1.8)	23.700 (1.6)	46,000 (3.4)	180,000 (12.9)

The investments in technology that would be necessary to meet the requirements were determined from an analysis of 23 "small" utilities. Of these, six would not meet the NIDWR. The quality problems and hypothesized treatments are listed in Table 14 and Table 15 gives the estimated economic impacts of these treatments.

Longworthy (20) surveyed water rates in Michigan and found that "Examination of the data reveals striking differences in rate changes among the dozen size ranges into which survey data were grouped. For example, in the 10,000 to 14,999 population group, the rate for 1000 US gallons of water ranges from $0.12 to $11.25, a ratio of 93 to 1. The information suggests that something other than cost is at play in setting water rates ..... It is unlikely ..... that 1000 US gallons can be produced and delivered for $0.12. Similarly $11.25 per 1000 US gallons could be too costly, but the figure may more nearly represent the real cost of serving water to that many consumers."

Two papers on wastewater reclamation were noted. Stenstrom et al (21) studied reverse osmosis as a method of reclaiming wastewater based on three years of operation of a small tubular reverse osmosis pilot plant using cellulose acetate membranes. Much of the experimental work was devoted to membrane cleaning methods. Using data from the pilot plant and 1979 data compiled by EPA an economic simulation model was developed for a plant producing 1 million US gallons per day (3785 m^3/day) of water consisting of 0.76 mUSgpd reverse osmosis product and 0.24 mUSgpd feed water. The blended mixture would meet the quality requirements for recycling of less than 750 mg/ℓ TDS. Using values of $12.00

TABLE 14

Utilities Selected for Cost Impact Analysis

Utility	Quality Problems	Hypothesized Treatment
	1	
1	Nitrate	Ion Exchange
2	Manganese	Chemical oxidation
3	Barium	Zeolite; lime softening
4	Barium	Zeolite; lime softening
5	Barium	Zeolite; lime softening
6	Total dissolved solids and fluorides	Reverse osmosis; activated alumina

TABLE 15

Estimated Economic Impacts for Small Systems

Item	Utility 1	Utility 2		Utility 3		Utility 4		Utility 5		Utility 6	
Water treated (m^3/day)	492	4430		1550		1700		250		4090	
Revenue-producing water (m^3/day)	416	2270		1022		1290		208		2950	
Proposal treatment technique	Ion Exchange (nitrate removal)	Chemical Oxidation	Ozonization	Ion Exchange Softening	Lime Softening	Ion Exchange Softening	Lime Softening	Ion Exchange Softening	Lime Softening	Activated Alumina	Reverse Osmosis
Construction cost for proposal treatment, U.S. dollars	101858	5913	71744	137000	622152	141512	643792	86518	368816	180772	1129902
Amonized capital cost for proposed treatment - dollars (7% ≥ 20 years)	9615	559	6773	12934	58727	13358	60769	8167	34814	17057	106655
Annual operations and maintenance costs for proposed treatment, U.S. dollars	21074	2528	7136	28547	80628	30094	83462	12612	49170	24937	204412
Total annual cost for proposed treatment, U.S. dollars	30689	3087	13909	41481	139355	43452	144231	20779	83984	41994	311065
Current annual total cost for water supply, U.S. dollars	16559	299387	299387	69328	69328	46470	46470	13078	13078	231006	231006
Projected annual total costs for water supply with proposed treatment, U.S. dollars	47248	302474	313296	110809	208683	89922	190707	33857	97062	273000	542073
Current unit cost for water supply U.S. cents/m^3	10.9	32.3	32.0	18.6	18.6	9.9	9.9	17.2	17.2	21.4	21.4
Projected new unit cost for water supply with proposed treatment, U.S. cents/m^3	31.1	32.7	33.8	29.7	56.0	19.2	40.4	44.6	127.7	75.3	80.1

per hour for labour and \$0.05 per kwh for electricity, an interest rate of 8 percent and a project life of 20 years the total system cost was found to be \$0.41/m^3. Details of the costs are given in Table 16.

Argo (22) discusses the cost of water reclamation by advanced wastewater treatment (AWT) as practiced at Water Factory 21 in the Orange County Water District in Southern California. The actual capital and operating costs are summarized in Tables 17 and 18 for a plant with advanced wastewater treatment capacity of 0.66 m^3/sec and reverse osmosis treatment capacity of 0.22 m^3/sec. Primary and secondary biological treatment costs are not included because this level of treatment is a prerequisite anyway. Argo gives the following basis for the tables. "Capital expenditures include all equipment and construction costs and all design and construction engineering costs ..... These costs reflect the actual construction contract award prices with no adjustment for inflation. Construction costs for the AWT plant and injection facilities, begun in March 1972, was \$13.2 million. All capital costs ..... have been amortized over a service life of 20 years at a 7 percent interest rate, with a plant factor of 90 percent ..... Construction of the reverse osmosis unit began in 1975 ..... The reverse osmosis construction costs are not adjusted for inflation and reflect actual contract award costs, with amortization at 7 percent for 20 years and a plant factor of 92 percent ..... Monthly operating costs were accumulated ..... during plant operation over a one year period." The year for which these costs were collected is not given but was probably 1978 or 1979. Labour rates are not given, but the prices of chemicals are listed and the costs of electricity and gas are given as \$0.03/kwh and \$0.20/mJ.

TABLE 16

Unit Costs

Treatment units/steps	Total Capital ($/year)	Total Capital	Operation and Maintenance ($/year)	Water Costs ($/$m^3$)
Vessels	295873	30135	26436	0.045
Surface Wash	32986	3360	1199	0.003
Media	12144	1237	0	0.003
Backwash	62114	6326	3408	0.008
Clarifier	110138	11218	2645	0.018
Coagulants	25312	2578	4219	0.005
RO unit	1011413	103015	315734	0.325
H_2SO_4	8841	900	1181	0.003
Chlorination	5904	601	4668	0.005
Cleaning	32496	3310	6038	0.008

Coagulation/clarification/filtration - $\$0.07/m^3$

Reverse osmosis system - $\$0.34/m^3$

Total system - $\$0.41/m^3$

TABLE 17

Water Factory 21 Capital and Engineering Costs

Treatment Process		Cost
Influent pipeline and pump station		$ 371,000
Lime clarification		826,000
Ammonia stripping		3,094,000
Recarbonation		421,000
Filtration		946,000
Granular activated carbon treatment		3,307,000
Adsorption	1,432,000	
Regeneration furnace	489,000	
Buildings, controls, other equipment	1,386,000	
Chlorination		396,000
Solids handling		1,848,000
Sludge pump station	109,000	
Thickener	57,000	
Centrifuges	135,000	
Furnace	600,000	
Building, controls, piping, electrical and other	947,000	
Reverse osmosis plant		3,000,000
Blending reservoir injection system		2,055,000
	TOTAL CAPITAL COST	$16,264,000

TABLE 18

Water Factory 21 - Capital and Operating Costs ($/1000 m^3)

	Chemical Clarification	Lime Recovery	Ammonia Stripping	Recarbonation	Mixed Media Filtration	Activated Carbon Adsorption	Activated Carbon Regeneration	Chlorination	Injection	Reverse Osmosis
Operations Labour	1.57	3.68	0.44	2.27	0.72	0.99	3.49	1.49	0.86	5.18
Maintenance Labour	0.66	2.78	0.66	0.66	0.66	2.00	2.01	1.13	2.77	-[e]
Maintenance Materials	0.67	3.34	0.67	0.67	0.67	2.37	2.37	1.26	3.33	35.08
Electricity	2.56	2.78	4.10[a]	3.08	0.68	3.03	1.01	0.97		72.91
Gas		5.74					2.45		2.24	
Chlorine				1.70[b]				6.22		0.13
Sulphuric Acid										3.94
Lime	2.72									
Sodium Hexametaphosphate										1.37
Polymer	0.60				0.07					
Standby Acid				0.26						
Alum					0.06					
Carbon							-[c]			
Total O & M	8.78	.27	5.88	8.64	2.86	8.40	11.33	11.07	9.20	118.49
Total Capital	6.02	9.33	15.58	2.12	4.76	11.81	4.38	1.17	4.53	45.34
Total Cost	14.80	27.60[d]	21.46	10.76	7.62	20.21	15.71	12.24	13.73	163.83

[a] When ammonia strip fans are operated, power costs are increased by $13.44

[b] When breakpoint chlorination is included, chlorine cost increases by $16.64

[c] If make-up carbon had been purchased, operating cost would be increased by $1.90

[d] The total cost of recalcined CaO is $90.41/metric ton.

[e] Maintenance contract

Des Jardin (23) discussed the impact of desalting on water supply in Alamagordo, New Mexico. The desalting plant will cost about 9 million US dollars to construct and operating and maintenance costs are expected to be about 3 to 4 million US dollars over the first four years of operation. The plant capacity will be 2 million USgpd (7570 m^3/day) when processing groundwater containing 1500 to 2000 mg/ℓ TDS. A very conservative estimate was made of savings resulting from reduction of hardness from 500 to 300 mg/ℓ. The average homeowner would save 114 dollars per year. This was based on savings in maintenance, soap useage, and municipal costs. Savings due to increased appliance life and elimination of water softeners were not included.

Wright and Biery (24) discuss a dual supply system which has been installed in Pelican Bay, Florida. When the water system was being planned it was realized that the available groundwater was adequate for irrigation purposes, but contained 900 mg/ℓ TDS and 278 mg/ℓ chloride and desalination would be required to make it potable. The dual water system has allowed provision of two different water quality levels thus reducing the required potable water treatment plant capacity from 4.5 mUSgpd (17,000 m^3/day) to 2.5 mUSgpd (9,500 m^3/day). Comparative economics of the dual system and a hypothetical single system are presented in Table 19. For the Pelican Bay situation, the dual system is considerably cheaper. The water quality design values are shown in Table 20. These have been achieved during two years of operation of the reverse osmosis plant.

TABLE 19

Comparative Economic Results of Dual Versus Single Water Distribution Systems

Item	Single System	Dual System
A. Construction Costs:		
1. Water supply and treatment plant	$3,500,000	$2,500,000
2. Water distribution system	1,952,000	2,791,000
Total	$5,452,000	$5,291,000
B. Annual Costs:		
1. Capital recovery 30 yrs at 7%	$439,377	$426,402
2. Operating and maintenance*	410,625	282,875
Total	$850,002	$709,277
C. Annual savings	$140,715	
D. Present worth of savings	$1,746,132	

* The operating and maintenance costs for treated water were estimated at $0.50/10,000 US gal. and $0.15/10,000 US gal. for irrigation water.

- Annual operating and maintenance cost estimates were based on estimated average water use over 30 years of 1.25 mUSgpd for potable and 1.0 mUSgpd for irrigation.

TABLE 20

Maximum Water Quality Design Values

Chemical Parameter	Raw Water	Treated Water	Reverse Osmosis Reject Water
Total dissolved solids	900 mg/ℓ	420 mg/ℓ	1,920 mg/ℓ
Chloride	278	120	632
Total hardness	471	135	1,344
Color	19	2	68
Total iron	0.1	0.0	0.4
Hydrogen sulphide	6	0.3	23
Sulphate	116	29	348

A note which appeared in Water/Engineering and Management (25) summarized the Water Supply Improvement Association's recent census of desalting plants. This shows that desalination facilities now contribute 2×10^9 USgpd (7.6×10^6 m^3/day) with 2200 plants in operation or under construction. Only plants producing 25000 USgpd (94 m^3/day) or more of desalinated water for commercial or domestic purposes are included. Distillation processes account for 76 percent of worldwide capacity with the remainder being mostly membrane technology.

RECOMMENDATIONS FOR FUTURE WORK

Spray freezing is a natural process controlled by the weather. Since the weather is a non-controlled variable, data must be obtained for at least five years if the results are to be statistically valid.

Weather variability can be illustrated by comparing the temperatures and wind speeds recorded over the last nine years. The Blucher, Frontier and outdoor laboratory data for the months of January, February and March are presented in Table 21.

The weather affects spray freezing in three major ways. These are:

1. The amount of water which must be sprayed per unit area of ice surface to maintain optimum temperature conditions in the ice mound depends on the rate at which freezing occurs. This rate is a function of the rate of heat transfer to the air from the water droplets and the ice surface. This heat transfer rate is a function of air temperature and wind velocity (wind chill).

2. Moderate to high winds disturb the spray distribution pattern. (This problem has been reduced, but not solved, by improved spray head design). If the wind blows from the same direction for a long time, the amount of water reaching the upwind side of the ice mound will be reduced. This, together with the cooling effect of the wind itself, will chill parts of the ice mound below the optimum

TABLE 21

Weather Variability

	Blucher						Frontier						Outdoor Laboratory					
	January		February		March		January		February		March		January		February		March	
Year	Temp °C	Wind kmph	Temp °C	Wind kmph	Temp °C	Wind kmp	Temp °C	Wind kmph	Temp °C	Wind kmph	Temp °C	Wind km	Temp °C	Wind kmph	Temp °C	Wind kmph	Temp °C	Wind km
1973	-14.8	11.0	-14.8	13.6	- 2.8	11.8	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	-13.3	14.5	-14.0	17.4	- 1.6	16.2
1974	-23.0	10.7	-14.9	10.6	-13.1	15.1*	-13.3	14.9*	- 4.3	12.2	- 3.6	14.3	-22.4	14.5	-13.8	16.3	-12.9	17.5
1975	-17.3	7.3	-19.4	9.0	-14.9	8.2	- 9.1	9.8	-15.3	7.6	- 6.9	8.1	-15.3	14.1	-16.9	16.1	-13.0	15.0
1976	-17.3	11.0	-12.6	13.6	-12.5	11.8	-10.6	11.7	- 3.9	13.0	- 4.8	13.1	-14.6	15.9	- 9.5	18.1	- 9.0	17.1
1977	-22.7	10.9	-10.2	9.1	- 6.2	12.5	-15.7	10.4	- 2.2	10.5	- 2.3	12.7	- 9.7	13.2	- 6.2	11.8	- 2.8	17.0
1978	-24.3	11.5	-17.6	13.4	- 8.2	9.6	-19.8	10.6	-14.9	12.5	- 6.4	8.6	-22.9	12.4	-16.4	15.6	- 5.1	13.4
1979	-23.5	9.9	-25.5	12.4	-11.5	11.5	-21.0	9.1	-17.9	11.3	- 3.6	10.4	-20.9	12.4	-23.2	13.5	- 8.5	13.7
1980	-21.1	13.8	-16.2	12.7	-12.5	14.5	-18.0*	12.5*	-10.6	8.5	- 5.1	11.2	-18.5	16.1	-13.7	13.9	- 9.9	15.3
1981	-14.9	13.2	-13.6	11.5	- 4.3	10.9	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	- 9.7	10.8	-10.3	12.8	- 1.3	11.3

n.m. - not measured

* - Partial

temperature for brine drainage and sometimes even below the eutectic temperature.

If the winds are gusty, lumps or nodes can form on the ice surface. Once formed, these are self-perpetuating and can grow into icicles, ice caves and ledges which will probably cool below the eutectic temperature.

3. If the ice mound is maintained above the eutectic temperature, some brine will drain from it during the winter. Draining continues during the melting period with some assistance due to the flushing action of the initial melt water. The drainage rate is slow, so if the weather is unusually warm early in the melting period the resulting increased melt water will dilute the brine drainage. This will reduce the purification efficiency.

Over the years evidence has accumulated to indicate that cumulative effects have been produced by brine seepage into the bases of the spraying areas. Apparently as additional spray freezing cycles were completed, the salts which had seeped into the bases of the spraying areas was being redissolved in subsequent years, reducing the effective purification efficiency. An additional factor is introduced at Blucher where the water table is high and in wet years can apparently be above the

bases of the spraying areas resulting in groundwater discharge. Presumably this occurred in 1979, when the apparent recovery from the unlined unit exceeded 100 percent. Results obtained from the unlined unit in 1981 are in agreement with the above observations. The apparent total recovery and purification efficiency were similar to those obtained in 1980. The polyethylene liner had no obvious effect except perhaps a slight increase in overall recovery. The liner panels were laid in place without sealing the joints, so the base of the ice mound could have been in equilibrium with soil water.

The lined unit produced an anomalous result. Overall recovery was about 80 percent, indicating some leakage through the liner, but purification efficiency was very high, the best ever attained at Blucher. Reasons can be postulated for the very good purification efficiency, for example, reduced re-solution of salts from the base because of a lower water table, warmer weather during the spraying season and better ice mound shape, but these reasons should also apply to the unlined and multiple units. Equivalent improvement in purification efficiency was not obtained for the lined and multiple units.

The Blucher multiple unit was operated for a fourth year. Overall recovery was lower than in previous years, but better quality product water was obtained. This can be explained by the brine seepage and groundwater discharge hypothesis mentioned above. Another factor influencing water quality is that this year the product water was pumped out as soon as it collected, which avoided mixing and reduced the time in which salts could be dissolved from the soil. With further use, the purification efficiency obtained in the multiple unit may deteriorate

as has been the case for the unlined unit. Another year's operations will provide additional information on the behaviour of a unit of this size with the water composition and climate existing at Blucher and will determine whether water quality will deteriorate.

The two smaller units should also be operated for comparison purposes and to try and resolve the reasons for the excellent performance of the lined unit this year. The results obtained with the polyethylene liner in the unlined unit do not justify repeating that experiment.

ACKNOWLEDGMENTS

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APPENDIX A

Meteorological and Ice Melt Data

TABLE A1

METEOROLOGICAL DATA

Date	Blucher			S.R.C. Climatological Station		
	Max. Temp. °C	Min. Temp. °C	Wind kmph	Max. Temp. °C	Min. Temp. °C	Wind kmph
Dec. 15, 1980				+ 5	- 6	9.5
16				+ 5	- 6	13.0
17				+ 4	-17	26.9
18	-12	-28	28.2	-17	-26	27.2
19	-24	-34	13.0	-23	-30	4.0
20				-22	-30	5.8
21	-19	-33	7.1	-19	-24	11.3
22				-19	-22	11.4
23	-20	-33	11.6	-21	-34	9.7
24	-20	-40	11.7	-18	-36	13.0
25				-18	-22	9.1
26	+ 7	-23	14.3	- 9	-19	12.7
27				+ 8	-13	18.4
28	+ 1	-19	8.9	- 9	-17	7.0
29				- 5	-13	5.3
30				+ 3	- 8	12.3
31				- 3	-11	9.9
Jan. 1, 1981	- 8	-29	16.3	- 9	-13	9.3
2				- 9	-20	16.8
3	-12	-24	13.1	-10	-20	14.8
4				- 4	-14	13.1
5	- 4	-13	12.3	0	- 9	10.5
6	- 2	-22	13.1	- 2	-19	19.4
7	-14	-22	18.9	-10	-15	10.4
8	-12	-23	4.6	- 9	-26	8.6
9	-12	-34	25.6	-16	-32	15.4
10				- 9	-16	11.3
11	- 9	-22	4.5	- 8	-18	9.8
12				- 4	-17	9.0
13	- 6	-21	15.6	- 2	-14	10.2
14				- 5	-16	2.8
15	- 7	-12	5.9	- 5	-10	7.8

TABLE A1

METEOROLOGICAL DATA

(cont'd)

Date	Blucher			S.R.C. Climatological Station		
	Max. Temp. °C	Min. Temp. °C	Wind kmph	Max. Temp. °C	Min. Temp. °C	Wind kmph
Jan. 16, 1981	- 7	-24	13.6	- 8	-15	16.0
17				- 4	-17	13.2
18	- 6	-20	19.1	- 3	-14	13.9
19				- 5	-15	5.4
20	- 7	-20	3.7	- 1	-15	8.5
21				- 3	-14	4.7
22				- 3	-15	6.1
23	0	-18	13.7	- 3	- 9	3.7
24				+ 2	- 4	8.4
25				- 1	- 6	13.2
26	- 4	-23	9.1	- 5	-12	8.3
27				- 7	-12	8.0
28	-10	-28	12.1	-12	-21	16.2
29				-11	-21	21.0
30	-11	-23	16.7	- 9	-16	7.3
31				- 9	-12	11.0
Feb. 1, 1981	-12	-31	8.3	-12	-22	11.9
2				-14	-28	4.6
3	- 9	-29	6.5	-13	-23	5.2
4				- 3	-20	17.4
5				- 3	-14	11.4
6	- 6	-31	17.0	- 7	-20	19.6
7				-20	-29	14.7
8				-19	-26	18.2
9	-23	-34	15.0	-24	-32	18.4
10	-27	-38	18.0	-22	-32	10.3
11	-26	-40	7.2	-22	-36	4.4
12	-21	-38	4.5	-18	-32	6.9
13				- 9	-27	14.3
14	+ 2	-31	11.6	+ 4	- 9	13.3
15				+ 4	- 5	15.3
16	+ 2	-10	12.3	+ 4	- 2	17.0
17				+ 2	- 7	9.3
18	+ 3	-13	8.0	+ 4	- 9	13.3
19				+ 6	- 7	15.3

TABLE A1

METEOROLOGICAL DATA

(cont'd)

Date	Blucher			S.R.C. Climatological Station		
	Max. Temp. °C	Min. Temp. °C	Wind kmph	Max. Temp. °C	Min. Temp. °C	Wind kmph
[illegible] 20,21,1981				+ 5	0	18.7
21	+ 3	-10	10.7	+ 4	- 2	15.0
22				+ 5	- 4	7.8
23				+ 1	- 7	13.1
24	- 1	-13	10.8	- 3	- 9	8.3
25				- 2	- 7	13.2
26	0	- 9	11.5	0	- 6	11.8
27				- 2	- 6	12.3
28	+ 1	- 9	17.2	+ 4	- 5	16.3
March 1, 1981	+ 1	-13	11.4	- 2	-11	10.1
2	+ 2	-13	9.2	+ 5	-10	15.0
3				+ 4	- 9	6.3
4	+ 2	-11	19.2	+ 2	- 3	22.3
5				+ 1	- 6	22.4
6	0	-10	11.9	+ 1	- 6	4.6
7				- 1	- 5	12.5
8				- 1	- 4	5.6
9				+ 3	- 5	2.6
10	+ 6	-13	9.4	+ 9	- 7	10.6
11				+ 8	- 1	19.7
12	+ 4	- 9	12.7	+ 7	- 5	8.6
13	+ 7	-11	5.4	+ 5	- 5	6.7
14	+ 6	- 7	8.3	+ 8	- 3	16.3
15	+ 6	- 7	11.1	+12	- 3	8.3
16	+10	- 7	5.0	+15	- 3	6.6
17	+13	- 6	14.5	+ 1	- 2	13.0
18	- 1	- 7	11.4	+ 2	- 5	15.9
19	- 1	-11	8.7	+ 7	- 7	13.1
20	- 2	-13	16.9	- 5	-15	23.3
21	-11	-29	16.4	-10	-21	10.2
22	+ 2	-29	13.9	- 5	-24	8.0
23				- 1	-16	6.9
24	+ 2	-18	5.5	+ 2	-12	6.0
25				+ 5	-12	7.1
26	+ 4	- 6	11.7	+ 5	- 2	15.1

TABLE A1

METEOROLOGICAL DATA

(cont'd)

Date	Blucher			S.R.C. Climatological Station		
	Max. Temp. °C	Min. Temp. °C	Wind kmph	Max. Temp. °C	Min. Temp. °C	Wind kmph
March 27, 1981	+ 4	- 7	8.3	+ 7	- 1	9.4
28	+ 8	- 7	8.0	+13	- 2	10.7
29	+ 9	- 4	8.5	+11	+ 4	9.1
30	+ 8	- 4	9.2	+ 7	+ 1	15.3
31	+ 4	- 6		+10	- 4	7.8
April 1, 1981	+11	- 6	20.2	+14	0	18.5
2	+12	- 7	12.9	+ 2	- 2	9.2
3	+ 2	- 6	10.5	+ 6	- 2	15.3
4	+ 2	- 6	9.1	+ 9	- 4	6.9
5				+14	- 2	15.9
6	+11	- 3	15.7	+11	0	32.1
7	+ 1	- 4	39.7	+ 6	- 2	31.0
8	+ 4	- 7	15.9	+ 9	- 4	12.8
9	+ 7	- 7	15.0	+10	- 2	24.9
10	+ 8	- 7	17.0	+ 3	- 3	10.6
11	+ 9	-13	16.3	+12	- 2	23.7
12				+ 6	- 7	19.3
13				- 3	-11	10.3
14	+10	-12	9.7	+14	- 8	12.6
15				+20	- 3	6.2
16	+13	- 2	7.6	+19	- 1	26.0
17	+16	- 7	18.0	+13	- 3	15.6
18				+11	+ 1	11.5
19	+ 8	- 7	7.9	+14	- 5	15.4
20	+12	- 1	24.2	+15	+ 1	22.9
21	+13	- 7	10.3	+14	- 2	13.1
22				+17	- 3	9.0
23	+19	- 1	10.3	+23	+ 4	13.0
24	+20	+ 1	18.5	+18	+ 6	27.6
25	+13	- 3	7.3	+16	- 1	8.7
26	+16	- 4		+16	0	7.4
27	+17	- 4	11.0	+18	0	10.9
28				+15	+ 7	11.8

TABLE A1

METEOROLOGICAL DATA

(cont'd)

Date	Blucher			S.R.C. Climatological Station		
	Max. Temp. °C	Min. Temp. °C	Wind kmph	Max. Temp. °C	Min. Temp. °C	Wind kmph
April 29, 1981	-	-	12.2	+16	+ 3	17.9
30				+15	+ 1	12.7
May 1, 1981	+22	- 2	15.2	+26	+ 6	24.4
2				+16	+ 6	10.1
3	+13	- 6	9.9	+10	+ 4	14.6
4				+14	- 1	5.4
5	+19	- 7	13.2	+17	- 2	11.3
6				+22	+ 8	27.0
7	+19	0	18.3	+20	+ 6	16.3
8				+11	+ 1	22.0
9	+13	-10	14.4	+14	- 3	14.8
10				+13	+ 3	13.7
11	+16	-10	7.7	+17	- 4	6.8
12				+19	0	8.3
13	+21	- 2	6.9	+21	+ 5	8.8
14				+19	+ 4	17.4
15	+16	- 4	28.9	+14	+ 1	33.3
16				+19	- 1	24.3
17	+23	- 1	19.8	+23	+ 4	19.3
18				+25	+12	23.7
19	+29	+ 3	14.8	+27	+12	18.0
20				+29	+ 7	4.5
21	+30	+ 6	16.8	+30	+ 9	17.5
22				+21	+ 9	27.1
23				+21	- 1	14.0
24	+24	- 3	13.2	+22	0	11.3
25				+25	+ 6	11.6
26				+27	+12	14.6
27				+29	+15	9.0
28	+27	+ 4	11.6	+19	+ 8	16.1
29				+17	+ 8	13.2
30				+22	+ 5	8.1
31	+24	+ 1	12.0	+21	+14	19.6
June 1, 1981				+23	+13	12.0

TABLE A2

Ice Melt Removals Blucher Lined 1981

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Sampled Imp. Gal.	Sample No.	TDS	Cumulative Volume Imp. Gal.
March 10	11:00	Started pumping				
11	13:50	9,480	9,480	BL-1	7,866	9,480
12	14:00	8,790				18,270
14	11:45	2,690	11,480	BL-2	4,309	20,960
15	11:30	8,610				29,570
16	13:00	8,310	16,920	BL-3	2,573	37,880
17	14:30	8,550				46,430
18	13:30	3,520	12,070	BL-4	2,628	49,950
19	11:08	2,250				52,200
20	11:10	2,280				54,480
20	11:10	Pump shut off, frozen lines				
26	14:05	Pump restarted				
27	12:05	12,060	16,590	BL-5	4,334	66,540
28	13:40	10,730				77,270
29	14:05	14,070	24,800	BL-6	2,383	91,340
30	11:30	12,850				104,190
31	13:45	14,380				118,570
April 1	15:40	15,040				133,610
2	14:20	16,000	58,270	BL-7A	1,267	149,610
3	13:35	1,270				150,880
5	11:10	9,950				160,830
6	13:10	15,750	26,970	BL-7B	658	176,580
7	13:30	12,780				189,360
8	14:00	5,880	18,660	BL-8	917	195,240
9	12:40	7,600				202,840
10	8:50	7,900	15,500	BL-9	820	210,740
13	9:20	16,680				227,420
13	9:20	Pump shut off, frozen lines				
15	9:25	Pump restarted				
16	11:00	26,190	42,870	BL-10	628	253,610
18	13:45	40,330				293,940

TABLE A2

Ice Melt Removals Blucher Lined 1981

(cont'd)

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Sampled Imp. Gal.	Sample No.	TDS	Cumulative Volume Imp. Gal.
April 19	11:00	10,930				304,870
20	14:40	15,320	66,580	BL-11	535	320,190
22	14:15	26,380				346,570
23	14:00	13,690	40,070	BL-12	800	360,260
24	15:15	22,330				382,590
26	12:00	27,640				410,230
28	13:45	23,030				433,260
30	13:45	18,260	91,260	BL-13	985	451,520
May 2	11:50	16,050				467,570
4	10:50	9,950	26,000	BL-14	1,026	477,520
6	13:30	10,340				487,860
8	13:50	10,580	20,920	BL-15	922	498,440
10	9:50	4,510				502,950
12	11:05	5,320				508,270
14	14:15	6,750	16,580	BL-16	802	515,020
16	11:30	5,320				520,340
18	16:15	8,870				529,210
20	15:30	7,630	21,820	BL-17		536,840
22	13:50	6,580				543,420
26	14:00	4,200				547,620
29	9:00	4,520	15,300			552,140

TABLE A3

Ice Melt Removals Blucher Unlined 1981

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Pumped Imp. Gal.	Sample No.	TDS ppm	Cumulative Volume Imp. Gal.
March 10	10:00	Started pumping				
11	13:50	1,480	1,480	BU-1	15,172	1,480
13	13:40	3,950				5,430
14	11:45	15,610	19,560	BU-2	4,710	21,040
15	11:30	18,250				39,290
16	13:00	19,000	37,250	BU-3	4,017	58,290
17	14:30	19,330				77,620
18	13:30	18,280	37,610	BU-4	2,841	95,900
19	11:08	12,790				108,690
20	11:10	7,590				116,280
20	11:10	Shut off, frozen lines				
26	14:05	Pump restarted				
27	12:05	15,090	35,470	BU-5	4,290	131,370
28	13:40	11,170				142,540
29	14:05	15,650	26,820	BU-6	2,689	158,190
30	11:30	14,070				172,260
31	13:45	16,520				188,780
April 1	15:40	13,970				202,750
2	14:20	15,580	60,140	BU-7	1,409	218,330
3	13:35	1,740				220,070
5	11:10	14,370				234,440
6	13:10	22,030	38,140	BU-8	1,748	256,470
7	13:30	12,770				269,240
8	14:00	7,990	20,760	BU-9	2,341	277,230
9	13:40	9,960				287,190
10	8:50	7,690	17,650	BU-10	2,246	294,880
13	9:20	18,920				313,800

TABLE A3

Ice Melt Removals Blucher Unlined 1981

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Pumped Imp. Gal.	Sample No.	TDS ppm	Cumulative Volume Imp. Gal.
April 13	9:20	Shut off, frozen lines				
15	9:25	Pumps restarted				
16	11:00	22,600	41,520	BU-11	3,194	336,400
18	13:45	40,700				377,100
19	11:00	7,730				384,830
20	14:40	9,540	57,970	BU-12	3,706	394,370
22	14:15	15,070				409,440
23	14:00	7,560	22,630	BU-13	3,324	417,000
24	15:15	10,680				427,680
26	12:00	11,000				438,680
28	13:45	11,100				449,780
30	13:45	10,340	43,120	BU-14	3,104	460,120
May 2	11:50	10,250				470,370
4	10:50	6,650				477,020
6	13:30	7,120	24,020	BU-15	2,826	484,140
8	13:50	1,210				485,350
10	9:50	2,830				488,180
12	11:05	3,450				491,630
14	14:15	4,410				496,040
16	11:30	2,360				498,400
18	16:15	2,730				501,130
20	15:30	600	17,590	BU-16	2,408	501,730

TABLE A4

Ice Melt Removals Blucher Multiple 1981

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Sampled Imp. Gal.	Sample No.	TDS ppm	Cumulative Volume Imp. Gal.
March 10	15:00	Started pumping				
11	13:50	49,500	49,500	BM-1	6,433	49,500
13	13:40	50,200				99,700
14	11:45	40,100	90,300	BM-2	5,270	139,800
15	11:30	46,300				186,100
16	13:00	50,700	97,000	BM-3	5,894	236,800
17	14:30	21,700				258,500
18	13:30	49,000	70,700	BM-4	4,975	307,500
19	11:00	38,500				346,000
20	11:10	32,900				378,900
20	11:10	Shut off, frozen lines				
27	12:05	Pump restarted				
28	13:40	52,300	123,700	BM-5	3,447	431,200
29	14:05	50,000				481,200
30	11:30	42,900				524,100
31	13:45	53,200				577,300
April 1	15:40	51,700				629,000
2	14:20	9,500	207,300	BM-6	2,421	638,500
3	13:35	72,050				710,550
5	11:10	141,140				851,690
6	13:10	80,130	293,320	BM-7	1,297	931,820
7	13:30	38,740				970,560
8	14:00	69,890	108,630	BM-8	1,780	1,040,450
9	13:40	73,420				1,113,870
10	8:50	48,770	122,190	BM-9	2,014	1,162,640
13	9:20	181,100				1,343,740
13	9:20	Shut off, frozen lines				
15	9:25	Pump restarted				
16	11:00	80,850				1,424,590
18	13:45	138,680	400,630	BM-10	1,130	1,563,270
19	11:00	70,920				1,634,190

TABLE A4

Ice Melt Removals Blucher Multiple 1981

(cont'd)

Date	Time hrs.	Volume Removed Imp. Gal.	Volume Sampled Imp. Gal.	Sample No.	TDS ppm	Cumulative Volume Imp. Gal.
April 20	14:40	84,420	155,340	BM-11	1,299	1,718,610
22	14:15	110,000				1,828,610
23	14:00	48,850	158,850	BM-12	1,404	1,877,460
24	15:15	132,400				2,009,860
26	12:00	42,040				2,051,900
28	13:45	87,010				2,138,910
30	13:45	84,170	345,620	BM-13	1,140	2,223,080
May 2	11:50	86,790	86,790	BM-14	977	2,309,870
4	10:50	71,720	71,720	BM-15	996	2,381,590
6	13:30	56,920				2,438,510
8	13:50	73,100	130,020	BM-16	895	2,511,610
10	9:50	27,120				2,538,730
12	11:05	33,450				2,572,180
14	14:15	41,550	102,120	BM-17	820	2,613,730
16	11:30	37,690				2,651,420
18	16:15	58,830				2,710,250
20	15:30	44,160	140,680	BM-18		2,754,410
22	13:50	37,410				2,791,820
26	14:00	19,340				2,811,160
29	9:00	10,380	67,130			2,821,540